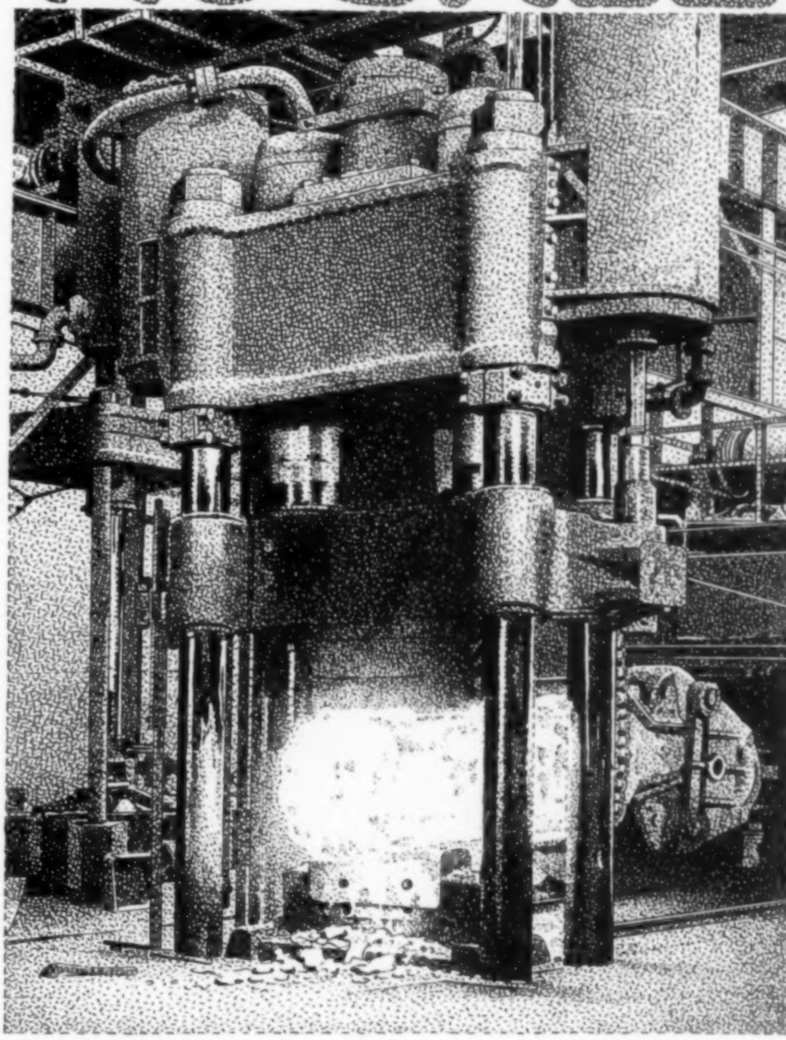
METAL PROGRESS



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Cover by Carl Sorenson; Inspired by large hydraulic forging press in plant of Struthers Wells Corp., Warren, Pa.

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Wrought Heat Resisting Alloys for Gas Turbine Service

THE newer alloys which have been developed for the highly stressed rotating parts of gas turbines (which include jet propulsion "motors" and gas engine superchargers) cannot be discussed in detail of analysis and properties because of security regulations in effect at the time of writing. However, the metallurgy involved in the development and application of these materials can be reviewed. In this review a compilation has been made of the significant properties of the older alloys which are not under secrecy restrictions, many of which can be used in parts of the new structures. In this article "base line" data are presented which describe the properties of these older materials so that engineers can readily see if there is any possibility of using them in contemplated structures requiring service at high temperature and definite loadings, and so that the newer alloys can be properly evaluated and compared by metallurgists and the designing engineers working on gas turbines and machines for other types of extra severe service.

The writer believes that many of the older compositions have potentialities for use in this new and extended field which have not been generally recognized, largely because data of the type presented herein have not been readily available. We have the strange, but not unfamiliar, situation wherein a complete laboratory test story is available to those who have a right to inspect the record on a number of *new* materials which are relatively untried in service, yet comparatively few laboratory tests exist on similar materials which have been marketed for years on the basis of service performance!

It is not the writer's intention to minimize the importance and significance of the newly developed alloys, since the advances which have been made are well worth the tremendous effort which has been spent on their discovery and development. Since 1941 he has been a member of the Subcommittee on Heat Resisting Alloys of the National Advisory Committee for Aeronautics, and in that time this group alone has made an intensive study of more than 100 new compositions. A number of these alloys have already been successfully applied to the gas turbine field. Additional work, done under the auspices of the War Metallurgy Committee and the National Research Council, has been equally comprehensive and successful. Fortunately, the entire development has been coordinated to avoid duplication, and has received the whole-hearted collaboration of the alloy steel industry — which, in itself, has made enormous advances in the production of heat resisting alloys, both new and old, since the start of the war.

We would not have the present attractive prospects of the gas turbine industry without new alloys for the highly stressed rotating parts. However, it is obvious that where the loads or temperatures are lower or less critical in other parts of the assembly, or where resistance to scaling is the only criterion, it will often be unnecessary to use these newer and usually more expensive materials. For instance, in the first Elliott gas turbine† the blades, rotors, shafts, bolts and some of the highly stressed duct work are from one of the newer alloys, but ordinary 18-8 is used in other ducts and the sealing strips, 25-20 and 28% chromium-iron in the combustion chambers, S.A.E. 4130 (1% Cr, 0.20 Mo) in ducts which withstand service up to 1000° F., nickel

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†See the line drawing in "Metallurgical Problems in Gas Turbines" by J. F. Cunningham, Jr., in the September issue of *Metal Progress*, page 486.

tubes in the regenerator (also at 1000° F.) and ordinary carbon steel or gray iron castings in the compressor parts and adjacent ducts.

The gas turbine above mentioned, operating at 1200° F. with an over-all thermal efficiency of about 29%, develops 2500 hp. (shaft). It is the first independent power gas turbine ever operated in the United States, and the first gas turbine to be built for marine purposes in the world. It has been accepted by the Navy after extensive tests; Ronald B. Smith and C. Richard Soderberg have described its operating conditions quite completely[1], and although the 1200° F. cycle is justly considered a real achievement, made possible by the newer materials, additional plants are being built to operate at 1350° F. and 1400° F., and will employ still newer and superior materials. The stresses in all these units are calculated at 6000 to 8000 psi. max. and the expected life is ten years, so that the design requirements are exactly analogous to steam turbine practice.

[1]References on page 1095.

Although a review of the data on the older materials will demonstrate that many critical parts of these new turbines must be made of the newer alloys, other parts can be designed with the older compositions, more or less standardized, and we are not certain that even for the highly stressed parts it will always be necessary or desirable to use the newer, scarcer and more expensive alloys. Ultimately, the power gas turbine must stand on its own feet in economy (first cost), and we must learn to take advantage of every possible saving in cost and fabrication of raw materials. We must keep in mind that any new alloy must be consistently forged and otherwise fabricated in the large sizes required before it can be considered commercial.

Also, we are somewhat chagrined to learn that our former enemies have apparently devised successful gas turbine structures without the benefit of new, super-strong materials. American engineering ingenuity will inevitably respond to this challenge. The need for higher operating

Table I — Composition of Wrought Heat Resisting Alloys

Type	Name		C	Mn	Si	S	P	Cr	Ni	Others
1015	Low Carbon Steel	Range:	0.10/0.20	0.30/0.60		<0.055	<0.045			
		Typical:	0.15	0.45	0.20	0.040	0.020			
C-Mo*	Carbon-Molybdenum Steel	Range:	<0.35	0.30/0.80	0.20/0.50	<0.050	<0.040			0.40/0.60 Mo
		Typical:	0.15	0.50	0.30	0.040	0.020			0.50 Mo
502	4/6 Chromium-Molybdenum	Range:	<0.15	<0.50	<0.50	<0.030	<0.030	4.0/6.0		0.45/0.65 Mo
		Typical:	0.12	0.45	0.30	0.020	0.015	5.0		0.55 Mo
410	12% Chromium Steel	Range:	<0.15	<0.60	<0.75	<0.030	<0.030	10/14	<0.60	
		Typical:	0.10	0.50	0.35	0.020	0.015	12.50	0.20	
430	18% Chromium Iron	Range:	<0.12	<1.00	<1.00	<0.030	<0.030	14/18	<0.60	
		Typical:	0.10	0.40	0.50	0.015	0.015	17.0	0.20	
446	28% Chromium Iron	Range:	<0.35	<1.00	<1.00	<0.030	<0.030	23/30	<0.60	>0.10 N
		Typical:	0.12	0.50	0.50	0.010	0.015	26.0	0.30	0.125 N
302	18-8 High Carbon	Range:	0.08/0.20	<2.00	<0.75	<0.030	<0.035	17/19	8/10	
		Typical:	0.12	0.40	0.35	0.015	0.015	18.0	8.5	
304	18-8 Low Carbon	Range:	<0.08	<2.00	<0.75	<0.030	<0.035	18/20	8/10	
		Typical:	0.06	0.50	0.60	0.010	0.010	18.0	9.0	
325	17 Metal	Range:	<0.45	<2.00				7/10	19/23	
		Typical:	0.40	0.50	1.00	0.020	0.020	8.5	20.0	
347	18-8 Columbium†	Range:	<0.10	<1.50	<0.75	<0.030	<0.035	>18.0	>8.0	Cb: 8 × % C
		Typical:	0.08	1.25	0.60	0.010	0.020	18.5	11.5	0.85 Cb
316	18-8 Molybdenum	Range:	<0.08	<2.00	<0.75	<0.030	<0.035	>16.0	>10.0	2.0/3.0 Mo
		Typical:	0.07	1.50	0.60	0.015	0.015	18.0	13.0	2.5 Mo
309	25-12	Range:	<0.20	<2.00	<3.50	<0.030	<0.035	22/24	12/15	
		Typical:	0.15	1.50	1.75	0.015	0.015	23.0	13.0	
310	25-20	Range:	<0.25	<2.00	<2.00	<0.030	<0.035	24/26	19/22	
		Typical:	0.12	0.55	1.75	0.015	0.015	24.5	20.5	
330	15-35	Range:	<0.25	<2.00				14/16	33/36	
		Typical:	0.20	1.50	0.20	0.020	0.020	15.0	35.0	
Inconel	Inconel	Range:	<0.15	<1.00	<0.50			12/15	>75.0	Note *(a)*
		Typical:	0.08	0.25	0.25	0.015		13.0	79.5	

*A.S.T.M. specification A182-44, Type F-1.

†18-8 Titanium (A.I.S.I. Type 321 with at least five times as much titanium as carbon) is generally considered equivalent to 347, but must be welded with 347 electrode, and has given trouble in the form of castings and welded tubing.

(a) Maxima are 0.50% copper and 9.0% iron; typical values are 0.20 and 6.5% respectively.

temperatures is unavoidable if better thermal efficiencies are to be had, but there need not always be corresponding increases in metal temperatures. Elaborate cooling schemes are possible, along with other devices. The situation is somewhat analogous to that existing in valves for reciprocating aircraft engines, where the 13% chromium, 13% nickel, 3% tungsten basic material must have a hollow stem filled with sodium for cooling, a stellited seat for hot wear resistance, a nichrome plated head for corrosion resistance, and the stem must be nitrided for wear resistance. In this way, a relatively inferior material is made to operate under conditions of temperature, corrosion, wear and stress which would be considered impossible from a study of the test data on the alloy steel itself.

Accordingly, we proceed to a description of the older heat resisting alloys and the tests and procedures which have been devised to describe and evaluate the characteristics of materials for high temperature service.

Table I lists 15 of the standard wrought compositions most widely employed in heat resisting structures today. Although low carbon steel is included primarily for reference purposes, it was the first "high temperature" alloy. Large quantities are still employed in piping, boilers ("firebox and flange steel"), steam fittings, blower casings, and wherever temperatures can be kept to 1000° F. max. and stresses are of a low order (not to exceed 2000 psi. at 1000° F. and 8000 psi. at 800° F., if ten-year life is desired). Most of these materials have been available for at least 20 years. Of course, improvements in analyses have been made; Table I lists present ideas about proper chemical limits. Some recent changes have been necessary to correct defects which showed up in service. For instance, the addition of 0.50% molybdenum to the 4 to 6% chromium steel greatly reduces its tendency to become brittle under load at temperatures above 800° F., and has enabled this relatively inexpensive material to maintain its top position in tonnage used in the petroleum industry.

The columbium addition to 18-8 is likewise a relatively recent improvement, necessitated by premature service failures from embrittlement or intergranular deterioration. This grade, and the similar titanium modification, has been available for about ten years.

The molybdenum addition to 18-8 stems back to work about 18 years ago, but only within the last six years have we arrived at a full appreciation of its properties and, what is more important, learned to modify the analysis so that it can be commercially fabricated.

The important automotive and aircraft engine valve steels are not included in this tabulation because these are special-purpose alloys which are not widely applied in other directions. The two most popular are silcrome (9% Cr, 3% Si) and the alloy containing 13% Cr, 13% Ni, 3% W. Their prime requirement is good hot hardness, which is not needed for most other high temperature work, and is a property which does not correlate with the other more important properties.

Table II — Specific Gravity and Thermal Coefficients

Coefficient of thermal expansion in in./in./°F. × 10^{-6}

Coefficient of thermal conductivity in Btu./sq.ft./hr./°F./in.

Type	Specific Gravity	Expansion in Range:			Conductivity at				
		70/600	70/1200	70/1800	212	392	572	752	932
1015	7.80	7.20	8.36	9.48*	346				
C-Mo	7.80	7.35	8.07	8.25*					
502	7.80	6.98	7.31	7.65*	254	250	245	238	234
410	7.70	6.98	7.32	7.56	174	180	186	193	
430	7.70	6.05	6.65	7.30	181	182	182	182	182
446	7.60	6.05	6.67	7.56	145	152	159	166	169
302	7.90	9.83	10.40	11.2	113	122	131	139	149
304	7.90	9.83	10.40	11.2	113	123	132	142	150
325	8.00	9.44	9.75	10.2*					
347	8.00	10.20	10.9*	11.7*	112	122	133	143	154
316	8.00	9.05	10.3*	11.2*	108				145
309	7.90	8.75	10.3	11.4	104				
310	7.90	8.41	9.84	10.4	90	98.5	106	104	120
330	7.90	7.91	9.03	9.98					
Inconel	8.51	7.08	8.43	9.45	107	115	123	134	144

*Extrapolated value.

Table II lists such physical constants as specific gravity, coefficient of thermal expansion and coefficient of thermal conductivity — essential information for the designing engineer.

Table III describes the heat treatment, microstructure, maximum temperature for continuous exposure to the atmosphere (oxidation), corrosive properties and some principal applications. Oxidation resistance is very important, and is one of the first things which must be considered in high temperature service. For instance, 4 to 6% Cr-Mo (Type 502) shows higher creep and rupture resistance above 1000° F. than other straight chromium-iron alloys with higher chromium contents, but cannot be exposed to oxidizing conditions for more than a few hundred hours at temperatures above 1150° F. without being seri-

Table III — Heat Treatment, Microstructure, Oxidation Resistance, Applications

Type	Usual Heat Treatment	Principal Microstructure	Maximum Service Temperatures: For Oxidation Resistance	Maximum Service Temperatures: In Other Atmospheres	Special Corrosive Properties	Some Notable Applications
1015	1550, furnace cool	Ferrite + carbides	1000	900 in refinery service	....	Low pressure boiler tubes, still tubes, piping
C-Mo	1550, furnace cool	Ferrite + carbides	1100	1000 in refinery service	....	Boiler tubes, superheaters, steam piping, still tubes
502	1550, furnace cool	Ferrite + martensite transformation products	1150	....	Lacks sufficient chromium for surface stability at high temperatures or in strong corrodents	Still tubes, oil lines, pump bodies, air preheaters, heat exchangers, superheaters
410	1800, oil or air quench + 1000/1200 draw	Ferrite + tempered martensite	1250	....	Good resistance to wire drawing and cavitation. Corrodes by pitting	Reaction chamber liners, pump parts, valves, steam turbine blading, compressors
430	1450, air cool	Ferrite + carbides	1550	....	Highly resistant to oxidizing acids. Subject to embrittlement between 800 and 1400° F., and grain growth above 1600° F.	Nitric acid equipment, furnace parts
446	1550, air cool	Ferrite + carbides + nitrides	2000	1800 in sulphur gases	Very brittle at room temperature. Maximum resistance to oxidizing acids or gases	Catalytic chemical process equipment, thermocouple wells, pyrometer tubes, soot blower elements, carrier sheets
302	2000, quench	Austenite + carbides	1650	poor in oxidizing exhaust*; bad in reducing exhaust*	Easily sensitized to intergranular attack in range of 800 to 1500° F.	Still tubes, high temperature and pressure steam and oil piping, pump parts, exhaust valves, blowers, furnace parts, homogenizers
304	2000, quench	Austenite + carbides	1650	1300 in refinery service	Less easily sensitized than Type 302	Same as Type 302, plus distillation apparatus, bubble caps, trays, header boxes, hydrogenation equipment
325	1850, quench	Austenite + carbides	1500	....	Subject to intergranular stress corrosion. Particularly resistant to sour (high sulphur) oils	High pressure safety and relief valves, pump parts, oil field equipment, blowers, resistors
347	2000, quench	Austenite + carbides	1650	....	Permits welding and slow cooling from above 800° F. without sensitizing	Same as Types 302 and 304 where welding is required, aircraft exhaust manifolds
316	2000, quench	Austenite + carbides	1650	....	Disintegrates rapidly above 1650° F. Very resistant to pit type corrosion. Not immune to being sensitized	Paper pulp industry, supercharger nozzle boxes, chemical process equipment
309	2000, quench	Austenite + carbides	2000	....	Not immune to being sensitized	Fractionating towers, furnace parts
310	2000, quench	Austenite + carbides	2000	....	Not immune to being sensitized	Burner parts, combustion chambers, still tubes
330	2000, quench	Austenite + carbides	1900	....	Not easily sensitized. Absorbs sulphur from high sulphur gases	Furnace parts, blowers, thermocouple wells
Inconel	As rolled	Solid solution alloy	2000	2100 in reducing H_2 or CO; at least 1100 in steam; 1500 in oxidizing sulphurous; 1000 in reducing sulphurous	Good in oxidizing exhaust;* Good in reducing exhaust*	Bi-metal applications, furnace parts, exhaust manifolds

*Fuel is 10 cc. of tetraethyl lead per gal. ("Q" ethyl fluid with bromine and chlorine). 200 hr. total testing time, 1800° F. max., 650° F. min.

ously weakened by loss of section thickness.

A very important point is mentioned in the preceding paragraph. The creep data and "stress-to-rupture" data which indicate the superiority of Type 502 above 1000° F. to such alloys as 12% Cr, 18% Cr, and 28% Cr (Types 410, 430 and 446, respectively) were obtained from tests which did not extend beyond 1000 hr. In this length of time, the relatively poor oxidation resistance of Type 502 with only 5% chromium did not affect the results sufficiently to warn against extrapolation of the curves to stresses for expected service life of five or ten years.

If Type 502 were initially stressed to 2000 psi. at 1200° F., it would appear from the creep and rupture curves shown in Fig. 5 to 9 that even a structure with very close tolerances should last at least five years. Actually, however, the stress would gradually increase due to loss of metal section, and failure might occur in six months — a failure chargeable to oxidation rather than low strength of the sound remaining metal.

This simple example indicates why the factors of stress, strain, time and temperature must be taken simultaneously with many other considerations in high temperature design and metallurgy. This is illustrated by the square shown in Fig. 1. First, the designing engineer must specify his limiting conditions of stress, strain, time and temperature and then the metallurgist must select the proper material considering the factors listed within the square. It is well to note that "unknown factors" are acknowledged. This is a confession of ignorance on the part of the metallurgist which the designing engineer must include in his "factor of safety".

Fig. 1 — Metallurgical Considerations (Inside Square) to Satisfy the Designer's Demands (Outside of Square)

The most important tests used today in the evaluation of high strength, high temperature alloys are as follows:

Oxidation
Corrosion
Short-time tensile strength
Stress-to-rupture
Creep
Fatigue
Change of ductility under load, with time, temperature, stress and rate of strain.

Fig. 2 — Typical Diagrams of Test Programs Containing Information for Design of High Temperature Equipment

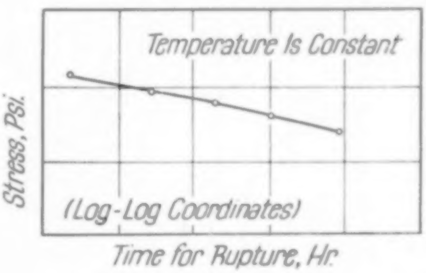


Fig. 2*a* — Stress-to-Rupture Plot, Single Temperature

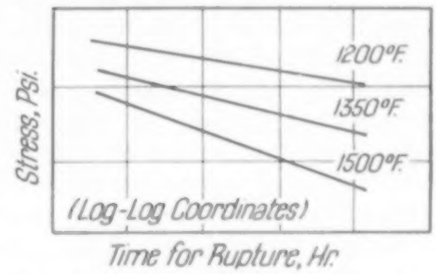


Fig. 2*b* — Variation of Slope, Stress-to-Rupture Plot at Various Temperatures

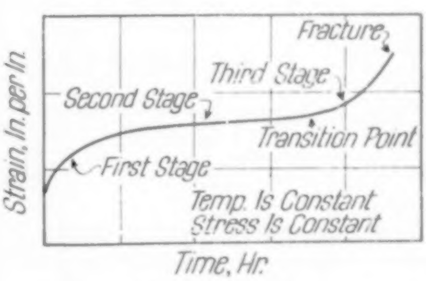


Fig. 2*c* — Plot of Typical Creep Test

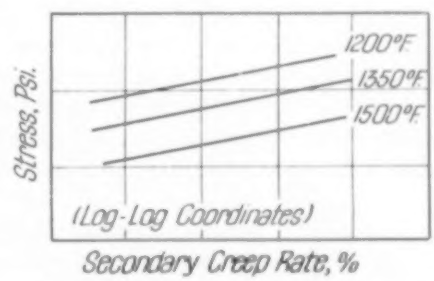


Fig. 2*d* — Variation of Slope, Creep Test (Secondary Creep Rate Vs. Stress) at Various Temperatures

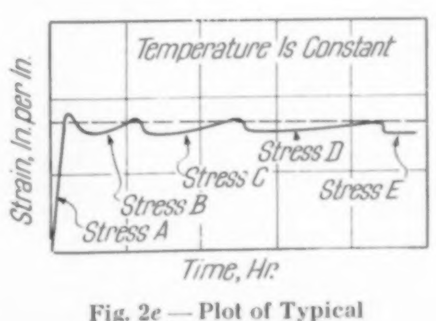


Fig. 2*e* — Plot of Typical Creep-Relaxation Test

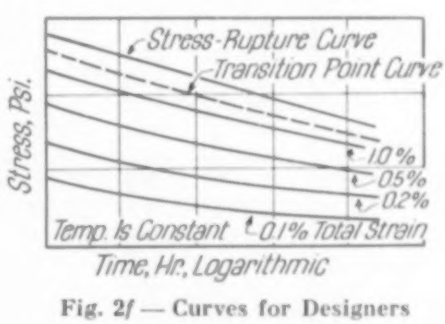


Fig. 2*f* — Curves for Designers

*Fuel is 10 cc. of tetraethyl lead per gal. ("Q" ethyl fluid with bromine and chlorine). 200 hr. total testing time, 1800° F. max., 650° F. min.

Table IV — Mean Values of Short-Time Yield Strength (0.2% Offset)

Type	Room Temperature	800° F.	900	1000	1100	1200	1300	1400	1500	1600
1015	42,500	24,000	23,500	20,000	14,000	10,000	7,500	3,500		
C-Mo	32,500	23,000	22,500	22,500	22,000	15,000	10,000	5,500		
502	27,000	20,250	20,000	18,000	16,250	12,250	10,250	8,000		
302	32,000	16,500	15,000	14,000	12,000	11,000	10,700	10,500		
304	31,000	15,500	14,500	14,000	12,000	11,000	11,000	10,500	10,000	
325	59,000	48,500	46,500	45,000	39,000	32,500	24,500			
347	41,500	32,500	31,500	31,000	28,000	26,000	24,000			
316	41,000	30,500	26,000	22,000	21,200	21,000	20,800	20,000	18,000	19,000
310	34,000	29,000	28,500	28,000	26,750	25,250	22,000	17,750	13,500	
Inconel	36,000	27,000	25,000	22,500	22,000	22,000	20,500	19,000		

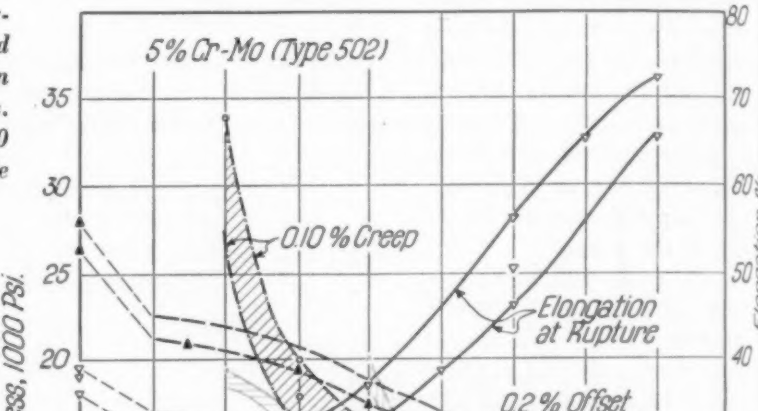


Fig. 3 — High Temperature Design Information for Type 502 Steel. In this and the next two figures yield and elongation are from short-time tensile strengths. Creep is for secondary creep per 1000 hr. Ranges include data judged reliable

In preparing this manuscript a complete review of the literature on the 15 alloys listed in Tables I to III was made, and the above properties tabulated for each material. The data were then critically appraised with reference to heat treatment and composition, and the properly representative values plotted for each alloy as illustrated in Fig. 3, 4 and 5 for the 4 to 6% chromium steel plus molybdenum (Type 502), the low carbon 18-8 (Type 304), and 25-20 (Type 310). In this way the spread in data could be determined and what might be called mean values obtained which have been tabulated in Tables IV to VII for all the materials. Some of these

Table V — Mean Values of Elongation at Rupture in Short-Time Tensile Tests

Type	Room Temperature	800° F.	900	1000	1100	1200	1300	1400	1500	1600
1015	36.0%	35.0%	38.0%	42.5%	56.5%	54.0%	59.5%	69.5%		
C-Mo	37.0	28.5	29.5	31.5	40.0	51.0	68.0	82.5		
502	37.5	31.0	30.5	35.0	42.0	51.0	60.0	68.5		
410	35.0	24.0	25.5	28.0	41.0	53.0	62.0	68.0		
430	32.0	29.0	32.5	37.0	50.5	61.0	67.0	70.0		
446	32.0	18.0	17.0	16.0	26.5	47.0	63.0	179.0		
302	60.0	36.5	35.3	34.0	31.5	32.0	32.5	34.0	35.0	37.0
304	61.0	46.0	45.0	43.0	40.5	38.5	36.5	33.0	31.0	38.5
325	32.0	28.0	28.0	27.5	30.0	37.0	46.5			
347	50.0	40.5	39.5	38.5	37.0	44.0	51.0			
316	60.0	45.0	44.0	42.5	36.5	33.0	33.5	35.0	38.0	26.0
309	54.0	49.0	47.5	46.0	38.0	31.0	31.0	31.0	31.0	32.0
310	46.0	37.0	38.5	39.0	35.0	28.5	28.5	31.0	30.0	
Inconel	49.5	45.0	42.0	37.5	16.0	5.5	7.0	12.0	23.0	32.0

mean or representative data have, in turn, been plotted in Fig. 6 to 10 so as to graphically compare the different materials. It will be observed that all the desired information is not available on each composition.

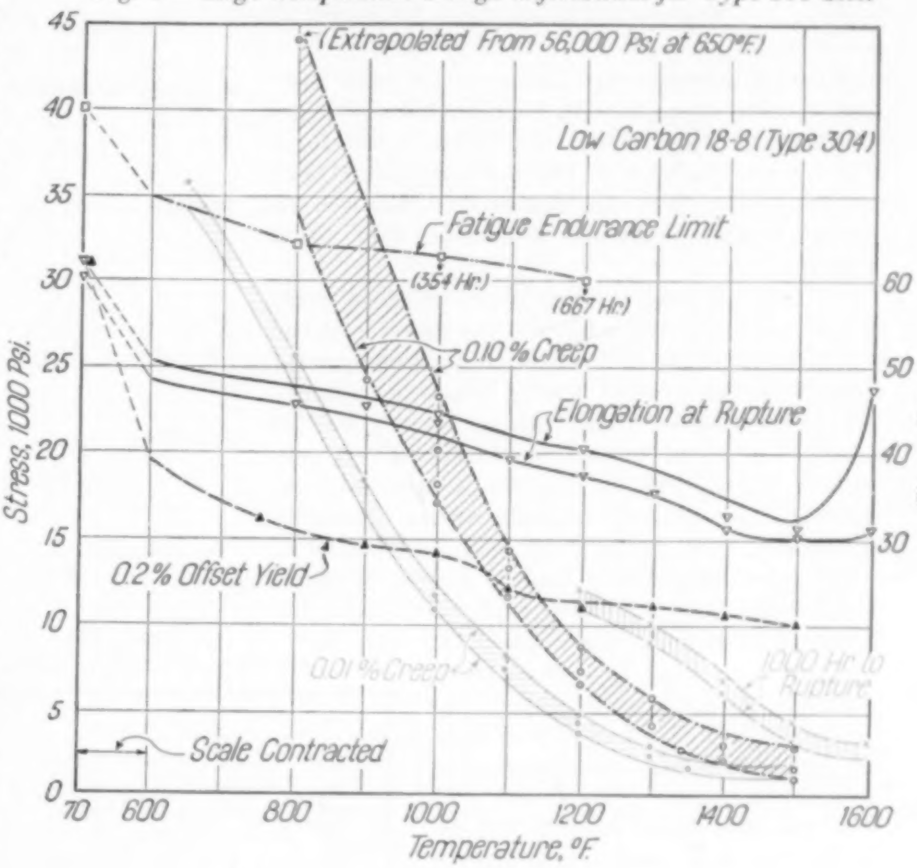
The importance of oxidation and corrosion testing has already been touched upon, with limiting temperatures being listed in Table III. A brief description of each of the other tests is given below:

Short-Time Tensile Test — This is the oldest high temperature test and is still widely used, although it has been generally discredited as a method of getting useful information on materials for service for any length of time above 1000° F. If the tests are carefully run under close control of temperature, rate of loading, and application of strain, the yield strength determined by the offset method can be plotted with the other high temperature data as in Fig. 3, 4 and 5. In this way, the temperature at which the creep strength for a secondary rate of 0.10% per 1000 hr. exceeds the 0.2% offset yield can be determined, and designs based on the short-time yield strength may be considered reliable below this temperature. In ferritic materials this temperature is about 800° F. and in austenitic materials about 950° F.

Where the information was available, per cent elongation was also plotted and the "mean" values tabulated (Table V) along with the 0.2% offset yield strengths for the various alloys (Table IV). This furnishes useful information for hot working or forming; dips in the curve or data out of line often give warning of temperature zones in which the alloy has a tendency to become brittle.

The early literature records a

Fig. 4 — High Temperature Design Information for Type 304 Steel



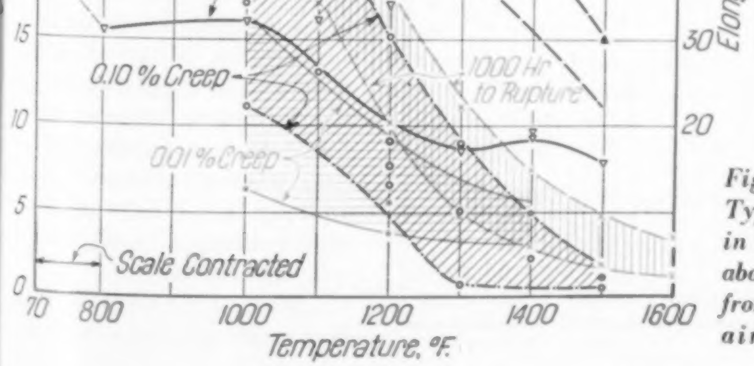
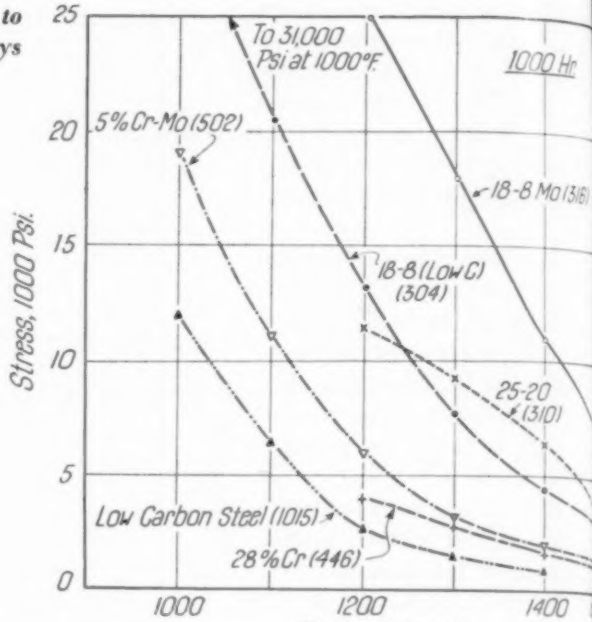


Fig. 5 — High Temperature Design Information for Type 310. Abnormal spread is due to difference in heat treatments; high creep and rupture values above 1000° F. are from material water quenched from 2150° F.; the low values are for material air cooled from 1700° F. (Reference 10)

Fig. 6 — Relation Between 1000-Hr. Life to Rupture and Temperature for Several Alloys



number of attempts to correlate short-time ultimate tensile strength with long-time creep information, but this is not a reliable procedure. Figures for modulus of elasticity are sometimes obtained from short-time tensile tests, but a more reliable method is by use of a tuning fork, to be described later.

Stress-to-Rupture — Early investigators made stress-to-rupture tests, but did not appreciate the significance of the data obtained, so that general interest in this type of testing has only occurred within the last ten years. An excellent paper by Clark, White and Hildorf[2] appeared on this subject in 1938. This is now the commonest test for high temperature strength and is generally considered to give the most useful information.

Figure 2*a* shows a typical stress-to-rupture plot, using data obtained with static breaking loads of decreasing size applied to a set of specimens at a given temperature. The rupture times are plotted against stress to give a straight-line relationship on log-log coordinate paper.

The short-time tensile test is really the first point on a stress-rupture curve. Smaller loads are then chosen in succession to give longer rupture times up to about 1000 hr. The longest tests ordinarily do not exceed 2000 hr. On tests of over 200-hr. duration the continuous elongation of the specimen is usually measured, from time to time, so that accelerated creep data are obtained.

Table VII — Stress for Secondary Creep Rate of 0.01% in 1000 Hr.

Type	800° F.	900	1000	1100	1200	1300	1400	1500
1015	12,500	8,500	3,500	800	300			
C-Mo	21,000	12,000	8,500	2,000	900			
502	19,000	15,750	8,500	3,500	2,000	1,500		
410		16,000	10,000	3,500	1,000	750		
430			7,000	4,500	1,600	1,000		
446					1,000	500		
302			9,500	7,800	6,500	4,300	2,300	800
304	24,500	17,000	11,250	7,250	4,000	2,250	1,500	1,250
325★			20,000	9,500	5,500	3,500	2,000	800
347				12,000	8,000	2,000		
316			15,000	12,000	7,000	4,000	2,700	1,500
309				10,000				
310			11,000	8,750	6,250	5,000	4,000	
330			20,500	14,000	8,000	4,000		
Inconel	48,000	28,000	14,000	6,000				

★Stock with 0.15% carbon

This test gives reliable data for high temperature structures which need only last 1000 hr. or less at full heat, and where relatively large clearances are provided. It also furnishes much general information on the high temperature behavior of the alloy and is highly useful in discriminating between materials and heat treatments. A large amount of data can be built up in a relatively short time, compared to other high temperature tests.

Most of the stress-to-rupture work has been done on

Table VI — Stress for Secondary Creep Rate of 0.10% in 1000 Hr.

Type	800° F.	900	1000	1100	1200	1300	1400	1500	1600
1015	20,000	12,000	5,500	1,000	500				
C-Mo	27,000	19,000	13,000	4,000	1,800				
502	29,750	18,250	13,250	8,000	3,500				
410		30,000	10,000	4,500	2,000				
430			8,500	5,100	2,100	1,500	800		
446		17,000	6,000	3,000	1,500	500	200		
302			21,000	14,000	10,000	8,500	4,000	1,000	
304	37,500	28,000	19,500	14,750	7,500	4,500	2,750	2,000	
325★			25,000	11,000	6,000	4,000	2,500	1,200	
347			22,500	19,000	10,500	3,800	2,500		
316			24,000	19,000	12,800	8,000	5,300	3,300	
309			17,000	13,000	8,800	4,500	2,000	1,200	
310			19,000	15,500	10,000	4,500	2,250	1,000	
330			24,000	16,000	9,500	5,500	3,500	2,000	1,500
Inconel		39,000	22,000	11,000	5,500	4,000	3,000	2,000	1,500

★Stock with 0.15% carbon

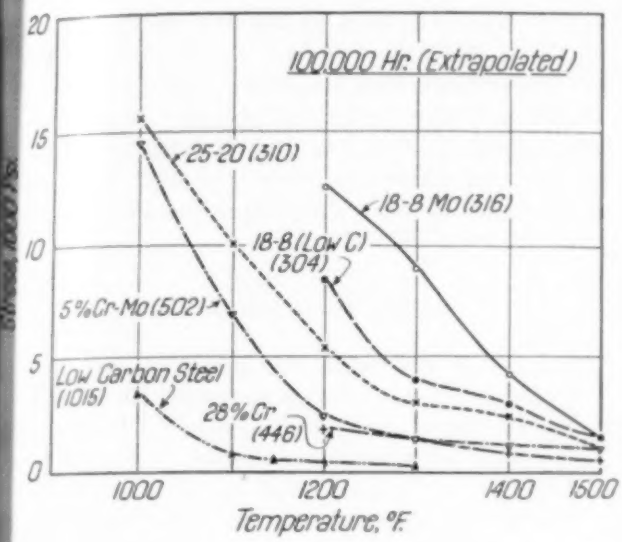


Fig. 7 — Extrapolated Values for 100,000-Hr. Life to Rupture

the newer materials, but data for seven of the older alloys are listed in Table VIII and plotted in Fig. 6 and 7. It is common practice to extrapolate stress-to-rupture data to give theoretical values for rupture at 10,000 and 100,000 hr., but this can be a very dangerous practice, due to the fact that nearly all high temperature materials tend to become brittle under load and change their microstructure as time goes on; premature failure may result accordingly. Progressive oxidation or corrosion also may not be fully detected in these relatively short-time tests.

Changes in the slope of the stress-to-rupture curve indicate either surface instability (oxidation) or structural instability (carbide precipitation, grain growth, phase change). When these changes are detected in the tests up to 1000 hr., proper warning is given, but there is no guarantee that the slope of the curve will remain the same as time goes on. Here again the engineer must resort to his factor of safety.

The tendency of a material to become brittle under load at a given temperature is demonstrated by the change in the elongation and reduction in area of the rupture specimens. This is caused not only by structural instability, but also by strain-hardening effects — if the tests are below the recrystallization temperature. In austenitic materials, it is not uncommon for an elongation of 25% and reduction in area of 30% in the short-time tensile test to be reduced to about 3% and 5%, respectively, after 1000 hours-to-rupture. The problem of anticipating how far this loss in ductility may progress is one of the most vital in high temperature design, and will be further discussed. The problem is not nearly so acute in ferritic materials for service up to 1000° F. as it is in austenitic materials for service above this temperature.

Figure 2*b* (page 1087) shows how the slopes of stress-to-rupture curves vary with temperature.

Creep — This test is so familiar as to warrant only brief mention. The common form of creep curve is illustrated in Fig. 2*c*. When a number of secondary stress-elongation rates have been determined, the data assume a straight line form on log-log paper, as illustrated in Fig. 2*d*. In contrast to stress-to-rupture data, the creep curves for various temperatures are generally parallel, although two groups of curves, each with parallel slopes, often exist — one for temperatures above and the other below the recrystallization temperature. Large amounts of creep data exist on the older alloys, and the mean values for all 15 compositions are listed in Tables VI and VII. Some of these values are plotted in Fig. 8 and 9.

Since creep tests are made under very close control of temperature, and since strain is very meticulously measured, many engineers feel that the results are too conservative, particularly since only a few installations are designed for *continuous* operation at temperature and *constant* stress. It should be kept in mind that we know very little about the effect of fluctuating temperatures and stresses, yet what little we do know indicates that fluctuations are harmful! Unfortunately, most creep tests are run for only 1000 hr., so here again extrapolations to longer times and higher rates are uncertain, although widely employed.

Table VIII — Stress-to-Rupture in 1000 and 100,000 Hr.

Type	1000°	1100°	1200°	1300°	1400°	1500°	1600°
	Stress for Rupture in 1000 Hr.						
1015	12,000	6,500	2,700	1,500	900		
502	19,000	11,000	6,000	3,250	2,000	1,500	
446			4,000	2,800	1,700	1,200	800
304			11,500	9,250	6,500	3,500	2,750
347		27,500	20,000	12,500			
316			25,000	18,000	11,000	7,000	4,000
310	30,750	20,500	13,250	7,750	4,500	3,000	2,250
	Stress for Rupture in 100,000 Hr. (Extrapolated)						
1015	3,500	800	500	500	300		
502	14,500	7,000	2,500	1,500	1,200	1,000	
446			2,000	1,500	900	500	300
304			8,500	4,000	3,000	1,500	1,300
347		16,500	11,000	4,500			
316			12,500	9,000	4,200	1,500	800
310	15,500	10,000	5,500	3,000	2,500	1,000	750

The best recommendation for creep data, as far as gas turbine design is concerned, is that creep has been the successful basis of design for *steam* turbines to operate up to 950° F. with an expected life of at least ten years.

The designer usually picks the stress which will result in a secondary rate of 0.001% per 1000 hr., or applies a factor of safety of 50% to

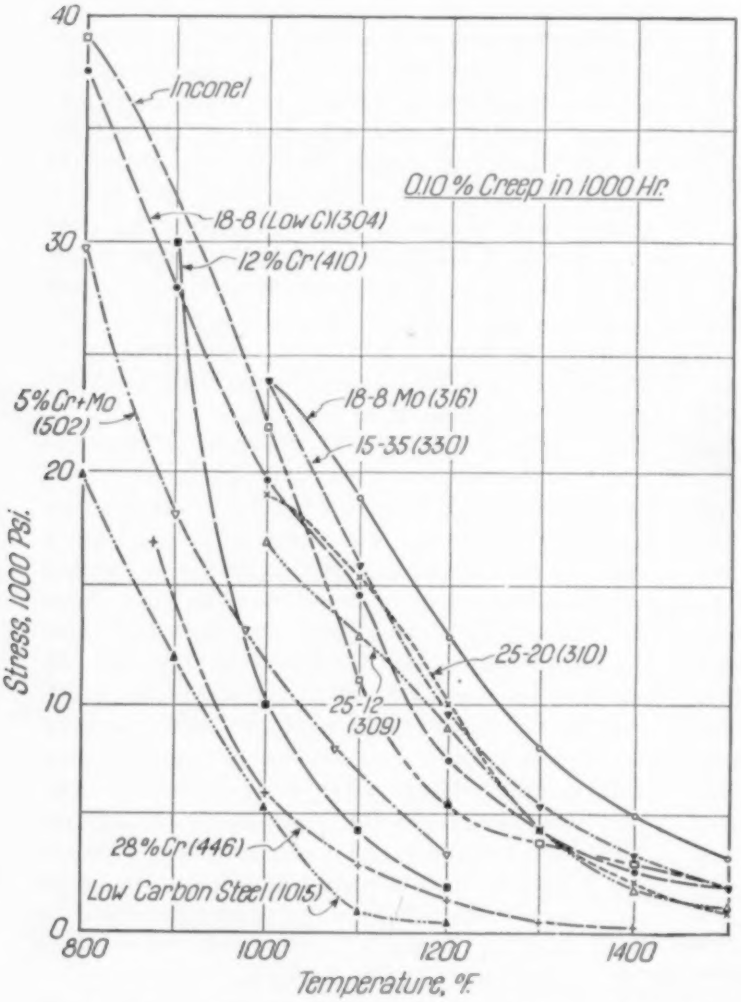


Fig. 8 — Stress for Secondary Rate of Creep of 0.10% in 1000 Hr. as It Varies With Temperature and Alloy. In the lower temperature range it is probably safe that this also holds for 1.0% creep in 10,000 hr.

the stress which will produce a creep rate of 0.01% in 1000 hr. "First stage creep" (Fig. 2c) is ordinarily disregarded. The extension in this first stage is usually about equivalent to the extension in the secondary stage for about 1000 hr. A change in slope upward of the secondary rate has been named the "transition point", and indicates that third stage creep is beginning and fracture may result quite abruptly.

In 1942 a series of 100,000-hr. creep tests at 842° F. was completed by the General Electric Co. on S.A.E. 4330 steel (0.31% C, 2.05% Ni, 0.83% Cr, 0.45% Mo, 0.54% Mn, 0.11% Si)[3]. A stress of 25,000 psi. gave evidence of third stage creep after about 70,000 hr., but stresses of 21,000, 17,000, and 13,000 psi. gave constant (or gradually reducing) secondary creep rates for the full test period of 100,000 hr.

High Temperature Fatigue

A review of the literature will show that the subject of high temperature fatigue has been generally neglected. The available information is plotted in Fig. 10. It will be observed that the data apply only to six compositions; the authority is noted on the curves.

The lack of data is due to three principal reasons: *(a)* The difficulty of testing — principally bearing troubles; *(b)* the length of time needed to establish an S-N curve showing an endurance limit; and *(c)* the assumption that at temperatures above 800° F. high temperature materials will fail by creep or simple rupture rather than by fatigue. Since service experiences have demonstrated that this third assumption is unwarranted, interest has been revived in high temperature fatigue.

Fortunately the Westinghouse Electric Corp. has developed an excellent high temperature fatigue machine, which employs a fixed cantilever, constant deflection principle vibrated by a balanced electronic system.[6] This rugged unit, without bearings, does not have the operational difficulties of the older rotating beam or rotating spring machines. Its frequency of 7200 cycles per min. is also more than double that obtained previously. Data from this machine are now available for Type 410 — the upper of the two curves for this alloy in Fig. 10.

The alarming thing about high temperature fatigue testing is that it is impossible to establish the horizontal line on the S-N diagrams (stress vs. number of cycles) within any reasonable time above 800° F. As is noted for the 12% chromium alloy at 1000° F., the curve is still falling at 500,000,000 cycles (1158 hr.). In other words, there is no well-defined endurance limit above 800° F. yet discovered. Accordingly, the metallurgist cannot give the designer the limiting stress below which the alloy will not fail from fatigue at a given temperature.

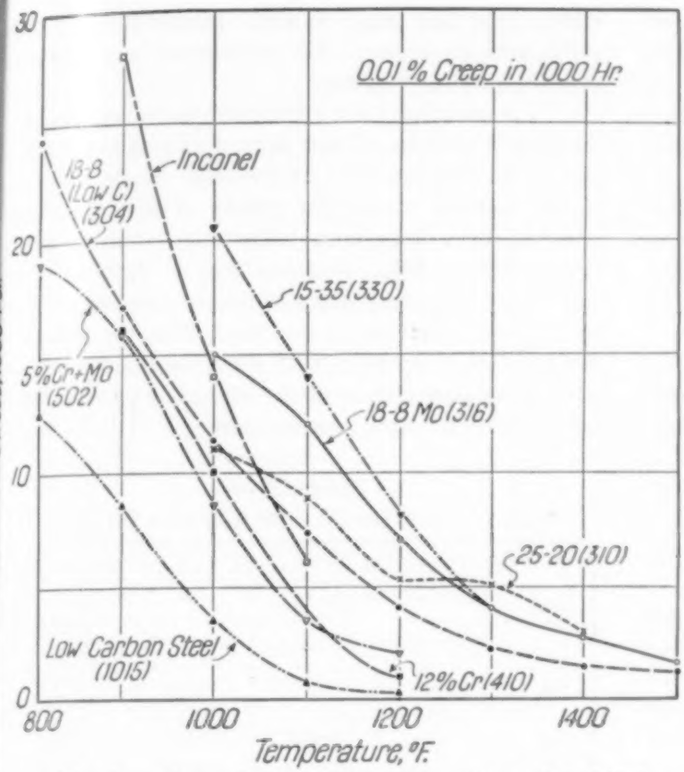


Fig. 9 — Stress for Secondary Creep Rate of 0.01% in 1000 Hr. as It Varies With Temperature and Alloy

Since all gas turbine structures are subject to fluctuating stresses, a great deal of additional laboratory work must be done on high temperature fatigue before these doubts are cleared up.

Special Tests

A number of special tests are applied to heat resisting alloys to determine their suitability for unusual conditions. Two of these, which are of general interest, will be described below.

Damping capacity is sometimes described as the "logarithmic decrement". In plain language this is the ability of an alloy to absorb energy through internal molecular friction and hence to cease vibrating. Alternate pulsations, particularly associated with partial admission turbines, can build up high vibrating stresses which may result in failure. Accordingly, the ability of a material to quickly "damp out" these stresses becomes important. This problem is closely associated with high temperature fatigue.

Damping capacity appears to be an inherent characteristic of each alloy, and is relatively unaffected by heat treatment or other processing variables. It is much higher in the ferritic materials than in the austenitic alloys. 12% chromium steel has one of the highest damping capacities known, and this may account, in part, for its success as steam turbine blading.

None of the austenitic compositions have good damping characteristics above 900° F., and their ability to damp gradually decreases with increasing time.

Damping capacity is ordinarily determined by use of a tuning fork; vibrations are set up and the length of time noted for the vibrations to be damped out. These tests also yield information on high temperature modulus of elasticity. The modulus at room temperature can be accurately determined by ordinary tension measurements and, upon heating, the frequency of the tuning fork will vary in proportion to the reduction in modulus.

Creep Relaxation — Figure 2*e* illustrates a typical step-down creep-relaxation test. Consider a bolt: The dotted horizontal line represents the initial bolting strain (room temperature) which is, of course, directly proportional to the stress. Since the relaxation test is used to evaluate the utility of an alloy for high temperature bolting service, we are interested in finding out the

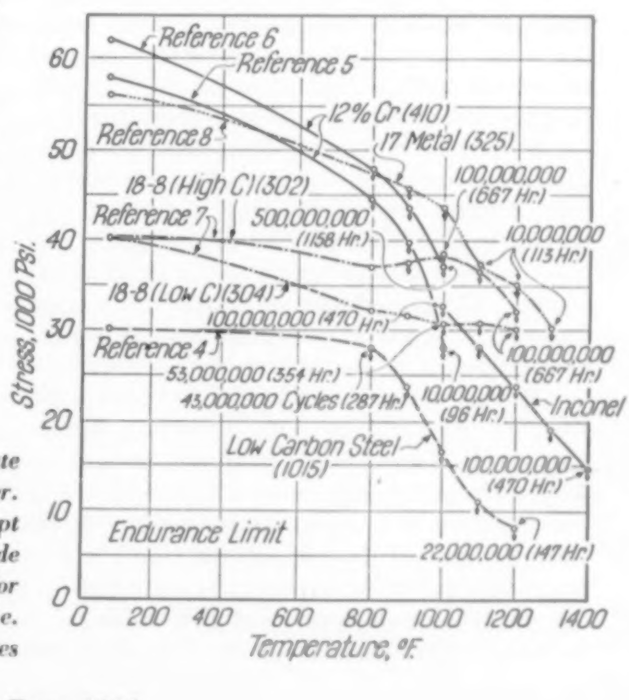


Fig. 10 — Fatigue Endurance Limit; Tests at High Temperature. Above 800° F. these curves indicate trends only; actual endurance limit, if it exists, is lower. Tests made with Farmer rotating beam machine except for 1015 and the lower curve for 410 which were made with a rotating spring machine, and the upper curve for 410 which was made with a fixed cantilever machine. Cycles and times of test programs are noted on curves

ultimate load to which a bolt will "relax" under this constant strain at temperature. In other words, we want to find out how quickly and to what extent the initial elastic strain is converted to permanent plastic strain. The residual elastic strain is, of course, what keeps the bolt tight — and if this falls below the minimum design figure, the joint will leak.

These tests may also be termed "restrained creep" tests. Stress A is larger than stress B, and so on, assuming that nothing happened during the period of higher stress that would modify its original ability to handle the lower stress. Secondary creep rates can then be obtained from the slopes of the curves for each stress. (As a matter of fact, the slope of the log-log plot of stress vs. rate of strain is usually somewhat flatter than the creep curve obtained from unrestrained creep.)

The modulus can be obtained from the slope of Stress A. Finally, these values can be substituted in the formula below, derived by E. L. Robinson of the General Electric Co., and the residual stress approximated after any given time period:

$$\text{Residual stress in psi.} = S = \sqrt[n-1]{\frac{bsn}{(n\text{-}1)rEt}}$$

n = slope of stress-rate log-log plot
b = elastic ratio of system (1.0)
s = nominal stress to cause creep rate r
r = nominal creep rate, 10^{-4} in./in./hr.
E = Young's modulus (at temperature)
t = time for residual stress, hr.

This formula gives good checks against a direct method for determining this property, as developed by N. L. Mochel, of the Westinghouse Electric Corp. In his method, a rigid frame of the flange material is employed through which an actual bolt is tightened up to the starting stress. The assembly is then placed in a furnace for a definite time, and the bolt then removed. The experiment is repeated for various times. The lengthening of the bolt is plastic strain which, subtracted from the initial elastic strain, gives a direct measurement of the residual elastic strain. (The modulus at temperature must be known, in order to calculate the stress which would remain in the bolt at temperature.)

Design Factors — When a large amount of stress-to-rupture data (with strain measurements) and creep information is available on a material, designer's curves can be constructed as in Fig. 2*f*. This method of plotting data gives the designing engineer a great deal of information for a given temperature. If he expects his structure to last ten years, as in power plant gas turbine design, he will stay far away from the "transition point" curve, and may have to limit his stresses to the 0.1% line to be sure his clearances will always remain within tolerance.

A more important reason why stresses should be chosen which will not permit extensive elongation over time periods above 1000 hr. is that we know so little about the ability of a material to deform for a long time without premature fracture (that is, from low ductility). If we calculate that after ten years we have not asked the material to deform more than 1%, we assume we are relatively safe, and we have a large background of experience in the steam turbine industry to warrant this assumption.

Table IX —
Ratios, Creep Strength C to Rupture Strength R

Type	C (1% in 100,000 Hr.) / R (100,000 Hr.)★		C (1% in 10,000 Hr.) / R (1000 Hr.)	
	1200° F.	1500° F.	1200° F.	1500° F.
502	0.80		0.58	
446	0.50		0.376	
304	0.47	0.835	0.65	1.33
347	0.725		0.525	
316	0.56	1.0	0.512	2.2
310	1.14		0.755	1.0

★Extrapolated

It is desirable, however, to make a large number of stress-to-rupture tests with relatively short times and high loadings, since we need a maximum of information in the shortest possible time. Table IX indicates the ratios of creep strength to rupture strength for six alloys at 1200° F. and 1500° F. These data would indicate that we can apply a factor of 50% to the extrapolated rupture strength for 100,000-hr. life to predict the creep strength for a secondary rate of 1% per 100,000 hr. There are indications that a similar factor applied to the rupture strength for 1000-hr. life will predict the creep strength for a secondary rate of 1% in 10,000 hr. Fortunately, these factors seem to increase as the temperature is increased.

Nevertheless, the writer believes that it is important to secure creep information for a long time at low stress once the lambs have been separated from the sheep by stress-rupture testing. For one thing, a material, or a given form of a material, may be relatively much better for low stress service than it appears to be from its tests at high stress.

Figures 3, 4 and 5 should be restudied in the light of our preceding comments. In particular it should be noted that with the exception of fatigue endurance limit and 0.2% offset yield for

18-8 (where only one set of values was available) the properties just discussed cover a rather wide spread on the graphs. It is highly important to recognize that this spread exists, and we are not thoroughly familiar with the characteristics of a high temperature alloy until the limitations of these "normal" variations have been established. After critically examining a large amount of the data on the 15 older compositions, it is the writer's opinion that a normal spread in stress-to-rupture properties can be as much as 50% of maximum, and that there may be as much as a 100% spread in the more sensitive property of stress to produce secondary creep of 0.01% in 1000 hr. These statements apply particularly to temperatures above 1000° F.

Figure 5, for 25-20, shows an "abnormal" spread purposely caused by heat treatment.[10] However, the profound differences applying to bars air cooled from 1700° F., as against bars water quenched from 2150° F., could easily apply between large and small sections as water quenched. It is often difficult to determine whether a deviation is "normal" or "abnormal", and the metallurgist must learn to understand and control the factors causing these deviations.

In addition to analysis (which may often be of secondary importance), heat treatment, section size, method of fabrication, and melting practice may cause wide deviations.

This study is concerned only with wrought materials, but it should be mentioned that castings of a given analysis usually have superior properties to the wrought alloy at temperatures above 1200° F. At the present time, however, castings are not being specified for long-time service under high and complex loading, because they cannot be fabricated reliably. As a matter of fact castings are employed widely in the low stressed parts of high temperature equipment and structures, and for parts loaded to high stresses where relatively short service life is required; interest will continue at a high level because of their relative freedom in analysis and form. Likewise, it should be stated that heat treatments which produce large grain size are favorable for resistance to deformation at working temperatures above 1200° F., but unfavorable to retention of ductility.

Conclusion

In this paper the metallurgy involved in the development and selection of high temperature alloys, especially for gas turbine service, has been examined. It has been found that if premature failure is to be avoided numerous and complex factors must be taken into account. In particular, ability to resist deformation (high rupture and creep strength) must be balanced against ability to relieve stress concentrations and to deform (high ductility).

Short-time tensile, stress-to-rupture, creep and fatigue data have been presented on 15 of the older alloys, along with physical constants and information about oxidation resistance. Although applications of these older materials to the rotating parts in the rapidly developing gas turbine field may be relatively limited, it is believed they will be liberally applied in other parts of the structure. Note also the widespread use of 18-8 + columbium steel in tail pipes, 18-8 + molybdenum steel in supercharger nozzle boxes, and inconel in the combustion chambers in recent jet engine and aircraft turbosupercharger designs.

The metallurgy of the newer materials, which will soon be generally available, is logically based on the older analyses discussed herein, so that this article may establish base line information by which the new "super alloys" can be properly evaluated and compared.

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(Continued on page 1126)

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Roentgen Observing Fluorescence Caused by Rays From Screened Cathode Tube

"IF the discharge of a fairly large induction coil be made to pass through a Hittorf vacuum tube, or through a Lenard tube, a Crookes tube, or other similar apparatus which has been sufficiently exhausted, the tube being covered with thin, black card-board which fits it with tolerable closeness, and if the whole apparatus be placed in a completely darkened room, there is observed at each discharge a bright illumination of a paper screen covered with barium platino-cyanide, placed in the vicinity of the induction coil.....The most striking feature of this phenomenon is the fact that an active agent here passes through a black card-board envelope which is opaque to the visible and the ultra-violet rays of the sun or of the electric arc. We soon discover that all bodies are transparent to this agent, though in very different degrees. Thick blocks of wood are transparent; a single sheet of tin-foil is also scarcely perceptible — it is only after several layers have been placed over one another that their shadow is distinctly seen on the screen. If the hand be held between the discharge tube and the screen, the darker shadow of the bones is seen within the slightly dark shadow-image of the hand itself. Lead of a thickness of 1½ mm. is practically epaque.....Of special significance in many respects is the fact that photographic dry plates are sensitive to the X-rays. Wherever it has been possible, therefore, I have controlled by means of photography every important observation which I have made with the eye by means of the fluorescent screen.....I possess, for instance, photographs of a set of weights enclosed in a box; of a piece of metal whose lack of homogeneity becomes noticeable by means of the X-rays, etc." — Extracts from a paper "On a New Kind of Rays", by W. K. Roentgen, published in the Proceedings of the Physical-Medical Society of Würzburg, Dec. 28, 1895. (Translation by G. F. Barker for Harper's "Scientific Memoirs", reprinted in "A Source Book in Physics", McGraw-Hill Book Co., 1935, page 600.)

1895 X-Rays' Golden Jubilee 1945

THE WORLD commemorates this month the 50th anniversary of that momentous event when, on November 8, 1895, a professor of physics at Würzburg Physical Institute established the existence of X-rays.

Exactly how WILHELM KONRAD ROENTGEN did discover these mysterious radiations is a matter which biographers have not succeeded in clearing up, but it is certain that he was the first to appreciate their significance and to differentiate them from the various types of radiation produced from early vacuum tubes. He was no lucky bungler, but a conscious explorer, proceeding with methodical steps toward the identification and isolation of a strange phenomenon.

GLASSER, a thorough and careful biographer, points out that ROENTGEN was repeating the experiments of HERTZ and LENARD with cathode rays, and "following LENARD's suggestion, he had covered the LENARD tube with black, opaque paper and had observed the fluorescent effect of the rays which passed through the paper on to a screen". It was later, when he applied the same technique to a HITTORF-CROOKES tube, that he discovered rays which would penetrate not only the paper cover but also other objects interposed between the tube and the screen.

Thus, ROENTGEN did not originate X-rays (the tube did that), nor was he the first to observe the fluorescent effects of rays produced by vacuum tubes. However, he was the first to observe and to note the significance of a type of discharge which could (as only he had demonstrated) penetrate almost all substances.

JACKSON, HITTORF, GOLDSTEIN, LENARD and others, according to GLASSER, had all observed — but had not explained — the fluorescence of certain materials when placed near HITTORF-CROOKES tubes. Usually, they were preoccupied with other problems and did not explore this phenomenon further. Moreover, it must be pointed out that LENARD, who had progressed far in his experiments and who had suggested placing the black paper over the tubes, had used a material on his screen which is not affected by X-rays but one which reacts strongly to cathode rays.

ROENTGEN's decision to use a barium platinocyanide screen, which is affected by X-radiation, was based on the fact that this material had been successfully used "to reveal the invisible rays of the spectrum, and I thought it a suitable substance to use in detecting any invisible rays a tube might give off". It can be seen that, since so many men had been working with X-ray without knowing it, all the more credit is due for his clear-headed, scientific elucidation of the subject. (As a side issue, it is interesting to note that HELMHOLTZ many years before, in his electromagnetic dispersion theory, had predicted the existence of X-rays and even described some of their properties.)

Several factors had to be present before ROENTGEN could culminate the process which produced his discovery — first, the high voltage induction coil developed by RUHMKORFF; second, the observation by HITTORF of rays emanating from cathode tubes; third, CROOKES' perfection of a tube with high vacuum; and fourth, the experiments of LENARD, already noted.

ROENTGEN's classical approach is epitomized in his own now-famous words, when queried by an American reporter:

"And what did you think when you observed this (fluorescent) effect?"

"I did not think," he responded, "I investigated!"

This was his attitude throughout his entire life, for he resolutely avoided being dragged into rash predictions concerning the applications for X-rays, since these might have exposed him to the attacks of others, whom he would be forced to answer in time-consuming defenses. He wished, rather, to be left to continue his research in X-radiation and other physical problems. He adhered to his principles without deviation, and produced many outstanding papers on subjects ranging from "Soldering Platinum-Plated Glasses" to "The Conductivity of Electricity in Several Crystals and the Influence of Irradiation Upon Them".

His success in the realm of physics is striking testimony to the short-sightedness of his early educators, who expelled him from the German equivalent of high school at the age of 16

for refusing to tattle on a classmate guilty of a minor prank. Needing high school credits for entrance into the University of Utrecht, he took a private tutor, but a man who had taken part in the suspension proceedings had, in the meantime, been appointed to act as judge of his entrance qualifications. Finally, he found entrance to the Polytechnical School at Zurich, Switzerland, where he met the brilliant experimental physicist, AUGUST KUNDT, who fanned his latent interest in physics. He later became KUNDT's assistant at the University of Würzburg, but, because of his lack of credentials, could not obtain an academic title. So much for an academic title, Germany, 1870!

When KUNDT moved to the newly-founded University of Strassburg in 1872, an institution less hampered by tradition, he took ROENTGEN with him, and it was there that he established a reputation in the German scientific world. There then followed a very gratifying offer from the same University of Utrecht from which he had been barred in 1862. He did not accept. In 1888, however, the University of Würzburg, which had refused him academic recognition at one time, made him an offer he could not decline, and it was there that he discovered the X-rays.

That the far-reaching effects of this event are still unfolding themselves is amply illustrated by an article in the current issue of the *Journal of Applied Physics* giving some important details about the 100,000,000-volt induction electron accelerator dubbed the "betatron", developed in the Schenectady laboratories of General Electric Co., after early developmental work by D. W. KERST, of the University of Illinois, and the General Electric X-Ray Corp. This unit, formerly hidden behind war secrecy, represents the peak reached thus far in high-intensity, short wave-length, X-radiation, and portends many future developments in deeply-penetrating radiography and radiotherapy. Only four years ago the 1,000,000-volt X-ray apparatus was put to industrial use; more recently the voltage of a similar unit was doubled; now comes a 50-fold further multiplication! It is indeed ironic that this German development should have been an important factor in defeating the Nazis. However, it is likely that, were ROENTGEN living in these times, he would have been a fugitive, as indicated by letters in which he deplores the prevalence of anti-Semitic prejudice.

Standing on the threshold of such important improvements in the X-ray field, and having seen its manifold uses in the metal industry during the war, it is a sobering thought that 50 years ago men foresaw most of the possibilities now in everyday use, and that one of the very first radiographs made by ROENTGEN was in the penetration of welded zinc, and it showed a considerable lack of homogeneity in the specimen! Later, in the summer of 1896, ROENTGEN sent to a friend some copies of a radiograph of a shotgun, revealing not only the bullets, but also fine irregularities such as small figures in the steel and the card-board disks in the shells. Even earlier in the same year, both the German and Austrian ministries of war called attention to the importance of the method to find defects in guns and armor plate. (The Carnegie Steel Works in Pittsburgh used X-rays as early as February, 1896, for experiments on steel.)

For some unaccountable reason, this early work with metals was followed through only sporadically. For example, Eastman Kodak Co. found so little industrial use of radiography, that special films were not justified until 1939. Those who pioneered the field had to be content with films produced primarily for medical work. Perhaps it was because flesh was easier to penetrate than metals, and the early tubes were far from powerful.

The rise of industrial radiography during World War II was nothing short of amazing. In quality control, research and inspection it has proven itself an essential tool. Radiography is standard practice in thousands of plants, which could no more dispense with X-ray or fluoroscopy than they could with welding or heat treating. Costly and inadequate destructive testing has thus been reduced to a minimum, and defective parts, instead of being discarded, are being re-worked. With the development of high-voltage machines, the latitude of films to varying thicknesses and densities has increased, while exposure time has been strikingly reduced. A 2,000,000-volt unit, for example, will do 8 in. of steel in 3 min., while a 1,000,000-volt unit will require 300 min.

Likewise in the research laboratories X-ray diffraction has only begun to show its capabilities. It is particularly adapted to the examination of those units of matter which are smaller than the wave length of visible light, yet will produce characteristic patterns when irradiated with X-ray. The nature, condition or behavior of most substances depends on the arrangement of atoms in a crystalline structure. Thus, diffraction can be used not only to determine the composition of a given substance, but also to follow, step-by-step, the changes which occur when a material is processed. It offers a new approach to the problems of quality control.

DAVID GOODMAN

By C. E. Ernst
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Wax Masking for Selective Copper Plating

MANY GEARS in aircraft engines, automotive and marine propulsion equipment, ordnance, machine tools, and peacetime machinery are selectively carburized to produce hard, wear resisting surfaces for contact areas, and tough, shock resisting properties in the remainder of the gear. For many years, two methods of obtaining selectively carburized areas were used. In one method, the part was rough machined, allowing extra stock in areas which were to remain soft, and then carburized. After carburizing, the part was finish machined. Those areas which originally were considerably oversize were machined down to the uncarburized core and therefore remained soft when the piece was later given the hardening quench. This method entails additional transportation from machining to heat treating for carburizing and again for quenching, causes difficulty in maintaining accurate locating points, and when this method is used, the part cannot be direct quenched from the carburizing heat, else it would be entirely too hard to machine.

The alternative method was to rough machine and copper plate all over, subsequently removing the copper by machining from the areas to be carburized. It was also necessary to remove copper from centers and from bores of gears if these areas were to be used as mounting surfaces in the subsequent finishing operations (as they almost always were) and this required a center or bore lapping operation before mounting on centers or arbors. It was impossible to achieve the highest degree of accuracy, as the soft copper made it difficult to maintain accurate points of location. Another attendant evil was the tendency to nick and scratch the copper plate during the handling and machining operations following copper plating. Carburizing gas then penetrated the punctured plate and caused hard spots in the gear, resulting in uneven wear and inaccurate and noisy operation. There was also the ever-present possibility, especially when making gears, of impregnating the bearing surfaces of the teeth with particles of copper carried through the cut by the cutter, where they would act as barriers to the carburizing gas and cause soft spots, equally as objectionable as hard spots.

The many shortcomings of these old methods were recognized by the Gleason Works many years ago and these practices were displaced in favor of the present routine of finish machining, followed by selective plating as the last operation prior to carburizing. A suitable method of stopping-off the copper in a practical, speedy, and inexpensive way was then sought. Four methods were investigated, namely, the use of tapes, stop-off lacquers, rubber masks, and wax.

The use of tape of any sort was abandoned because of the excessive amount of labor and time consumed both in applying it before plating and removing it after plating. The cost of material was high and the parts were often damaged by the tools used in cutting and placing the tape in position. Stop-off tapes have many uses in plating such as masking plating racks, but we found that they could not be economically applied for the selective plating of gears.

Stop-off lacquers of various types were experimented with but were found to be unsuitable for several reasons. The drying time proved an insurmountable obstacle from the production standpoint, especially since more than one coat was required. Brushing was much too slow. Spraying introduced other difficulties since, in order to prevent areas which were to be plated from being sprayed with lacquer, it was necessary to mask with tape or design spray jigs. Masking with tape was out; spray jigs are expensive and therefore only suitable for long runs of identical gears. Because of their necessarily light construction, such jigs suffer a high rate of mortality. Time consumption, high labor cost, and fire hazard, in addition to the difficulty of

Fig. 1 — Wax Pot With Wax Application Fixture (A, B, C) and Adaptor D for Gear. Gears EE are cleaned, ready for waxing; gear F has been selectively waxed. Note simple facilities and small space required

obtaining clean lines of demarcation at the edge of the lacquer — all these factors eliminated stop-off lacquers from further consideration.

The rubber masking method for selective plating was also considered, but after observing its operation in other plants it was decided to continue the wax method which we had been using with marked success for a number of years. At first glance, the rubber masking method seemed to afford a solution, but after careful consideration, it became apparent that its disadvantages outweighed its advantages in most gear applications except possibly for high production runs of identical gears. Where many and varied types of gears are plated, the storage and cataloging of rubber masks become a problem of no mean dimensions, requiring valuable space as well as man-hours. Furthermore, on anything except long production runs, there is the matter of cost to consider, since molding dies for rubber masks are expensive. Often changes must be made in such a mold to correct for leakage or fit; worn masks must also be replaced from time to time. Another objection to rubber masking is the number of necessary operations following plating. A dark smut tends to form under the mask during plating, and an additional cleaning operation is necessary after the masks have been removed. Masks must be cleaned and rinsed after each plating cycle. Again, unless the mask fits perfectly and has been adjusted with care — or after it has become slightly worn — a "flash" of copper as much as 0.0002 in. thick may be deposited under the mask. This must be removed by an additional operation, generally a chromic acid strip followed by a rinse. This entails the installation, maintenance, and control of another bath and introduces another hazard because if, by error, the gears are allowed to remain in the stripping bath too long, the thickness of copper in the plated areas will be reduced below the minimum requirements. Thus it is necessary, after stripping the "flash", to check thickness of plate by a Magne gage.

When first considered, the use of wax for masking prior to selective plating seemed to be the logical answer. However, we found that, while wax was being used extensively for this purpose in gear manufacture, it was often attended with mediocre results and was only used because nothing better was available. A little study indicated that insufficient attention had been given to the types of wax; waxes with high expansion were being used. The excessive shrinkage of these waxes on solidifying lifted the edges and the copper plate would later creep in on areas required to be plate-free. Other failures came from lack of adhesion, but this in turn was caused by the lack of thorough cleaning of the bare steel. The process was also extremely slow because the wax was applied by brushing; the time thus consumed was so great that the correct gear temperature for the wax application could not be maintained from beginning to end — even if the operator were aware that the temperature of the gear was important, a fact not generally appreciated at that time.

After some experimentation, a simple and speedy technique was developed and has been used for several years in many plants with marked success. Details will now be given.

A wax with high melting point is used, similar to Ceresine High Melting Point Wax, a product of the Standard Oil Co. of New Jersey. It is held at 240 to 260° F. in a rectangular dipping tank, electrically heated and thermostatically controlled. Gears are prepared for masking by running them through an electrolytic alkaline cleaning cycle and a hydrochloric acid dip and rinse (the conventional preparation for copper plating).

Before applying the wax, the clean gears must be at the correct temperature, which is 110 to 120° F. If the wax is applied to a cold gear, the rapid solidification with the accompanying contraction pulls the wax away from the base metal, particularly at the edges. On the other hand, if the gear is too hot, the wax will flow excessively and the resulting coat will be too thin.

These difficulties can be avoided if the gear is kept at a proper temperature, which can be

readily accomplished in several ways. For example, the cleaned gears may be placed in a holding oven. A warm water bath, controlled between 110 and 120° F., may also be used; such gears can be quickly blown dry with an air blast before wax masking.

In most instances, the operator who applies the wax also does the preliminary cleaning. He takes the gears directly from the hot rinse to the wax application fixture after quickly blowing them dry with an air blast. He obtains the desired temperature by varying the time of immersion in the hot rinse. Operators soon become adept at judging the correct temperature by a sense of feel.

For the purpose of rapid wax application, a simple, adjustable fixture, shown in the two photographs, was devised. It consists (Fig. 1) of a base plate *A* to which is hinged a back plate *B* which can be adjusted to any desired angle with the base plate. The back plate is fitted with a slide *C* which is adjustable for height and carries a stud at right angles toward the front, on which bushings *D* of various outside diameters, for accommodation of a range of bore sizes, can be placed.

After the correct bushing has been placed on the fixture and the latter has been adjusted for diameter and face angle to accommodate it, the gear is then placed on the bushing and lowered into the wax, its downward travel being limited by an adjustable stop. As shown in Fig. 2 the gear is then rotated by hand in the wax (wetting only those outside portions that need masking), raised, and removed from the fixture. This operation consumes but a few seconds. After cooling, the masked gear is given a quick acid dip and rinse and is ready for plating.

After plating and rinsing, the gear is placed in boiling water which quickly removes the wax. This completes the operation and the gear is ready for carburizing without further ado. The whole operation is fast and simple. Most gears, whether bevel, herringbone, or spur, can be wax masked on this fixture. Internal spurs must be wax masked by hand, with a brush.

Some waxes, such as Austrian Hard Dark Green Ozokerite, can be easily and inexpensively reclaimed. The procedure is as follows:

1. Wax, removed from the part by boiling water, solidifies on the water's surface when it cools. (If the removal tank is in service constantly, the wax may be skimmed periodically and solidified in cold water.) The wax is not usable in this state as a layer of sludge adheres to it.

2. A reclaiming tube is made of 4-in. seamless tubing, 40 in. long. One end is closed by welding a disk to it. The disk is drilled and tapped for a ¼-in. pipe plug. Two lugs are welded to the outside of the tube near the open end for suspension. If there is enough wax, several tubes may be used simultaneously by tack welding them together in a cluster.

3. Suspend the reclaiming tube vertically in a tank of boiling water with the top rim about 4 in. above the surface. Slabs of wax which have been removed from the cold water are broken up and dropped into the tube. After the tube has filled with melted wax, it should remain in the boiling water not less than 8 hr. to precipitate the sludge. It is then allowed to cool slowly.

4. Remove the pipe plug from the tube, immerse the tube momentarily in boiling water to melt the bond between wax and container, remove and invert the tube, and allow the cylinder of wax to slide out the open end.

5. An inch or two of sludge will be found at the bottom end of the reclaimed cylinder of wax. This is cut away and discarded. The remainder is as good as new.

Fig 2 — Back Plate of Fixture Has Been Tilted to Correct Angle for Bevel Gear, and the Operator Is Turning Gear to Wet Those Areas That Must Be Masked. Masked gears in left foreground

Wax masking, made practical by the procedure described, has been an important factor in successful selective carburizing of gears. The method has adapted itself with great facility, especially in plants where the variety of gears is great and the production runs limited in number.

Gears — which were formerly rough turned, plated all over, returned to machining for removing copper, carburized, machined again, then hardened — are now machined complete, selectively plated, carburized, and hardened. This has not only saved a tremendous amount of time, repetitive transportation and handling, but has contributed greatly to the high standards of precision now met by gear manufacturers.

By Cyril Stanley Smith
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Control of Explosive Atomic Energy

THE PUBLICITY on the atomic bomb has to a large extent been concerned with the physics of it, with rather unspecific references to the enormous engineering and industrial development that was necessary to make it an actuality. The sparse reference to the role played by the science and art of metallurgy may be attributed in part to the small glamour of our subject, and in part to the necessary secrecy regarding the actual processes of manufacture, which at present are the only real "secret" of the bomb.

There have been, however, extremely interesting metallurgical problems. Some of these arose in connection with the development of barriers for the separation of uranium 235 from the other isotopes of uranium by gaseous diffusion, the fabrication and "canning" of uranium for use in the plutonium-producing piles, and the preparation and shaping of the extremely valuable final products which are used in the metallic form. It was with the last of these that the metallurgists at Los Alamos were particularly concerned.

Although uranium is a most interesting metal, plutonium provided a unique and exciting problem. The metal, the first visible realization of the alchemist's dream, was completely unknown five years ago, and preliminary measurements of its properties had to be made with extremely small amounts of material.

Plutonium is strongly electropositive and reacts with most common refractories, yet it had to be produced in a state of extremely high purity. It is toxic by virtue of its radio-activity, and the personnel working with it need special protection. The danger of an unwanted and premature nuclear chain reaction leading to an explosion was always present. To complicate the problem further, the final shapes to be made were not known until shortly before they were actually produced.

In addition to our work with plutonium, the physicists made frequent demands for other special materials, and it seemed as if they delighted in selecting those that were particularly difficult to fabricate. Altogether, the life of a metallurgist at Los Alamos was exciting and full of interest.

The achievement of a satisfactory bomb by no means ends the possibilities of applied nuclear physics, or removes the need for metallurgical work associated with it. The entire field of nuclear power is now ripe for development and there will be demand for materials capable of withstanding conditions of temperature, stress and corrosion far more extreme than those that have hitherto been encountered in ordinary power plants, in addition to materials selected primarily because of their fissionable nuclei or because of high or low absorption of neutrons. The new problems, new methods, and new scientific horizons are fascinating. They can well claim our whole attention, but we must also recognize another aspect of our work.

Scientists and engineers, whether they wish it or not, are determining the fate of all mankind. It is their professional duty to see that the rest of society is aware of the significance of their work. They need not, indeed should not, become politicians, but as human beings they must make clear the enormous potentialities for good — or for sheer and utter destruction — that have been uncovered.

Those of us who have worked on the atomic bomb have seen the successful solution of a problem that kept us working through many periods of discouragement, and under conditions of urgency, secrecy, and discomfort that were

warranted only during wartime. We are not elated, but rather are appalled at our achievement! We know that what we have done, scientists and engineers of other countries can do sooner or later. Our temporary lead in time must not be confused with a permanent lead in fundamental knowledge.

The destructive powers of bombs have been raised three orders of magnitude in a single step without increased difficulties of delivery. If people can see, as is so plain, what will happen to their cities during a next war in which atomic bombs are used by both sides, they will demand that their statesmen establish suitable control mechanisms. War has always been a foolish, illogical and unsatisfactory method of settling international disagreements; it has now become too costly to be tolerated. We *must* realize this.

No thinking person should need the further evidence that a World War III would provide. Previous advances in the art of killing have been slow and continuous advances. Here is a sudden, discontinuous increase, a long leap ahead, and the shock would seem to be sufficient to make the need of action obvious.

Many competent and wise persons have written and spoken of the extreme urgency of the problem, yet in spite of this, many citizens of the United States are completely unconcerned — or even unaware that a problem exists. We *must* disturb this complacency! A glance at the photographs of Hiroshima and Nagasaki and a momentary reflection as to the effects of similar bombs (or the inevitably — perhaps thousandfold — improved bombs) on our own large cities, shows that the time is already here when weapons in the hands of nations need the same control as do weapons in the hands of individuals.

This is not idealism. The same old animal urge toward self-preservation should make all men demand proper control of this new weapon.

Protection against the explosion wave of nuclear bombs is impossible, though it may become possible to interfere with the delivery of some of them. Even if interceptive measures as effective as those used by the British against the V-1 bomb are used, the residual few per cent that get through the best defensive screen can still carry more destruction than an equivalent number of the largest raids dropping incendiary bombs. Moreover, such effective defense takes weeks to organize, yet seconds will serve to obliterate the nerve centers of a nation by surprise attack.

On the other hand, *control* is extremely difficult, yet not impossible. It will involve a great change in habits of thought and some degree of sacrifice of national prerogatives, yet it *must* be established. Lack of world-wide control will inevitably lead to the obliteration of important centers of communication, government and industry — and it is more likely to be our own cities than those of another country, unless we are willing to establish and maintain active defense, perpetually and continually, and to adopt a continuing wartime psychology and economy. The popular demands for the return of men in the Army and Navy, and for production of civilian luxury goods are demands for suicide if not accompanied by a most urgent demand for control of this new weapon.

Control is difficult politically, but it is certainly feasible physically. An international agency, backed by all peoples, with knowledge of all nuclear research and development, and with complete powers of inspection of mining and industrial enterprise, could render the building of bombs impossible.

This at least is the opinion of a vast majority of the scientists and engineers who have worked on the bomb.

Is the establishment of such control impossible, when the alternative is so dire and so obvious? We are not talking of the possible death of a few people in a remote part of the world; we are talking of our own annihilation as individuals and as a nation, and the loss of the cultural and material heritage of all mankind.

We should be scared enough to do something. Those who have first-hand knowledge of the bomb *are* scared.

"Discussion of the atomic bomb with Great Britain and Canada and later with other nations cannot wait upon the formal organization of the United Nations. These discussions, looking toward a free exchange of fundamental scientific information, will be begun in the near future.

"But I emphasize again, as I have before, that these discussions will not be concerned with the processes of manufacturing the atomic bomb or any other instruments of war.

"In our possession of this weapon, as in our possession of other new weapons, there is no threat to any nation. The world, which has seen the United States in two great world wars, knows that full well. The possession in our hands of this new power of destruction we regard as a sacred trust. Because of our love of peace the thoughtful people of the world know that that trust will not be violated; that it will be faithfully executed." — President Truman, Navy Day Address, Oct. 27, 1945.

By Henry T. Chandler
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Alloy Steel or Alloy-Treated Steel (?)

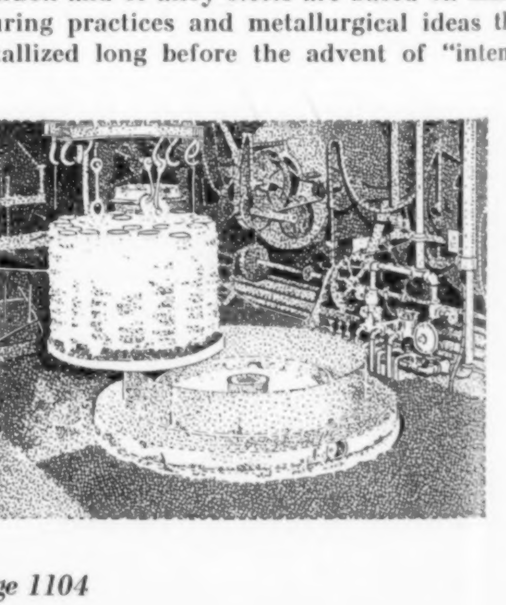
SO MUCH ATTENTION has recently been given by steelmakers, steel users, and interested metallurgists to the production and properties of steels after treatment with special reagents, and so many of these reagents or "intensifiers" have been used and urged by their sponsors, that it is high time an effort were made to clarify the situation, even if only to endeavor to fix upon a terminology that purchaser and producer can use, and so be able to talk the same language. For there is no question but that the present confusion in ideas is causing needless trouble and waste of energy.

There is also no question but that much of the trouble is due to the fact that, despite a considerable amount of intelligent research, there is no general agreement as to why these special reagents act as they do. The same or nearly the same result can be had in several different ways and with different proprietary reagents (alloys). Steelmakers know *how* to get the results; they do not know precisely *why* it happens so.

This is natural. Most advances in technology are well established by the so-called practical men before the systematic thinkers get around to explaining the techniques and relating them to the solid body of scientific fact underlying the art and industry. Furthermore, and because of the conditions imposed by war, there has not been the usual widespread interchange of ideas which would normally occur, with the development of this wide interest, through publication by technical papers, trade magazines and the like. Thus, even the few basic facts which have been disclosed by research are either unknown to metallurgists generally or at best only partially known.

Often, indeed, it is not necessary that the *why* of an operation be known, but in the case under discussion something more than confusion is desirable, because over 1½ million tons of the new "intensified steels" — as they have frequently been called — have been sold to truck, tractor and ordnance makers, and interest is spreading widely. I believe that this art of treating molten steel will continue to be practiced in one form or another in postwar times. If this is so, it becomes more and more necessary that such steels be adequately specified, so the purchaser can get what he expects, and the producer can clearly understand what he is expected to furnish. About the first step in reaching such an understanding is to agree upon a classification that will differentiate these steels from other more conventional types, for the difference between a normal steel and the same steel to which an intensifier has been properly added is indeed a difference of a high order (as will be shown presently).

Unfortunately, the present official definitions of carbon and of alloy steels are based on manufacturing practices and metallurgical ideas that crystallized long before the advent of "intensi-



fiers". I quote from page 4 of Section 10 on Alloy Steels of the "Steel Products Manual" of the American Iron & Steel Institute, as revised in February 1943:

Carbon Steel

Steel is classed as carbon steel when no minimum content is specified or guaranteed for aluminum, chromium, cobalt, columbium, molybdenum, nickel, titanium, tungsten, vanadium or zirconium, or any other alloying element added to obtain a desired alloying effect; when the specified or guaranteed minimum content for copper does not exceed 0.40%; or when the maximum content specified or guaranteed for any of the following elements does not exceed the percentages noted: Manganese, 1.65%; silicon, 0.60%; copper, 0.60%.

Alloy Steel

Steel is classed as alloy steel when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits: Manganese, 1.65%; silicon, 0.60%; copper, 0.60%; or in which a definite range or a definite minimum quantity of any of the following elements is guaranteed within the limits of the recognized commercial field of alloy steels: Aluminum, chromium up to 3.99%, cobalt, columbium, molybdenum, nickel up to 5.25%, titanium, tungsten, vanadium, zirconium, or any other alloying element added to obtain a desired alloying effect.

First, it is to be noted that the steels in each of these classifications may contain "any alloying element added to obtain a desired alloying effect". The distinction between the two classes, therefore, does not appear to be based upon *what* the steel contains but rather upon *how much* of each alloying element is present, and whether or not the amount is *specified* by the consumer and *guaranteed* by the producer. Under these definitions, steel classification is determined first of all by chemical analysis, and secondly by the implied assumption that the alloy content determined by analysis is essential (and therefore may be specified) to the properties of the finished "alloy" steel.

These official definitions therefore imply that steels are adequately defined, for the purposes of buying and selling, by the results of chemical analysis. While this supposition is true enough for steels containing substantial amounts of nickel, chromium, vanadium, molybdenum and other commonly used elements, it is far from satisfactory when applied to the intensifier alloys. In the latter case the relation between the amounts of the added elements which appear in the finished steel and the change in properties which results from the addition is not sufficiently precise to establish a basis for commercial specifications.

For example, the amount of Grainal No. 79* required for the full treatment of S.A.E. specification T-1340 may be as little as 1¼ lb. per ton of steel treated, or as much as 12 lb. per ton, depending upon the process by which the steel was made, and more specifically upon the state of its nitrogen and oxygen content. It is obvious that neither of the official definitions fits the example just cited. Certainly the intensifier alloy must be added to the steel if it is to produce any desired effect, and certainly if it is to be added that fact should be specified. At once guaranteed amounts and minimum amounts come into consideration and we may not, in consequence, include "treated steels" in the carbon steel group. However we are not much better off when we attempt to classify them under the present definition of alloy steels, for we have long been accustomed to identify usual alloy steels in terms of the *amount* of alloy contained, and in this example — which is by no means unique — this is not practicable.

Assuming for the moment that we know precisely what the word "steel" means, another difficulty with the above definitions is that they do not tell us what is meant by "alloying elements" and "alloying effect". Certainly the term "alloying effect" could be extended to include the changes in steel's properties brought about by the addition of intensifiers but, in my opinion, the common understanding of the term does not now do so. Possibly the definition maker may be excused for his inability to give immediately a precise and acceptable definition of "alloying effect", for Edgar C. Bain requires 300 pages to do so in his book on the "Functions of the Alloying Elements in Steel". Nevertheless the matter of precision in ideas and definitions cannot be dodged, for it is at the bottom (I am sure) of most of the uncertainties which now plague us.

At the risk of being accused of turning the clock back I would like to revert to some definitions proposed by Henry D. Hibbard in 1915 in his pioneering book "Manufacture and Uses of Alloy Steels". He says:

> Simple steel, often called carbon steel, consists chiefly of iron, carbon and manganese. Other elements are always present, but are not essential to the formation of the steel, and the content of carbon or manganese, or both, may be very small.
>
> Alloy steel is steel that contains one or

*The indulgence of the reader is requested in this use of proprietary names, hopeful that he will understand it is done not for advertising purposes but because it is desirable in this article to make specific rather than general statements, and the alloys so noted are the only ones about which the author is qualified to speak.

more elements other than carbon in sufficient proportion to modify or improve substantially and positively some of its useful properties.

Alloy-treated steel is a simple steel to which one or more alloying elements have been added for curative purposes, but in which the excess of the element or elements is not enough to make it an alloy steel.

While this is not perfect I believe it hits nearer the center of our present difficulties than

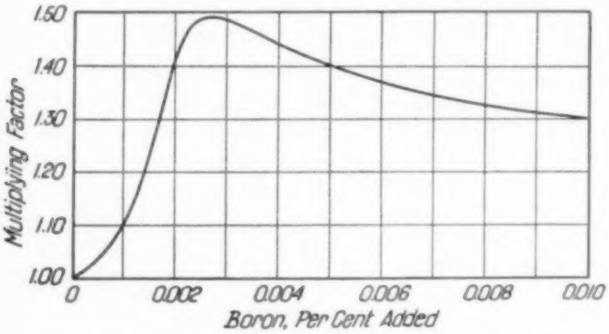


Fig. 1 (After Grossmann) — Multiplying Factors for Calculation of Hardenability of Steels Containing Boron

the longer A.I.S.I. definitions. It admits a class of steels to which alloys have been added but which are not defined in terms of alloy *content*. Let me clarify the terms somewhat:

I believe that if almost any purchasing agent would be asked to name some alloying metals that convert a carbon steel into an alloy steel he would not hesitate to say "nickel and chromium", and any experienced metallurgist would agree with him and could give a criterion that would differentiate between a nickel steel, a chromium steel, a molybdenum steel, or a tungsten steel, one or all of them, and (say) a steel to which aluminum or zirconium had been added. He would say that the effects of the former alloying metals (nickel, chromium, molybdenum or tungsten) are roughly proportional to the amount added, which is always substantial in commercial alloy steels and easily measured by analysis. On the other hand a little of the elements aluminum or zirconium in the contrasting category is sufficient — often a *very* little is sufficient, difficultly found by the analyst — and an excess of the element is no better, if not worse, in its influence on the steel's properties. An example of the latter is Fig. 1, taken from M. A. Grossmann's paper "Hardenability Calculated From Chemical Composition" contributed to the American Institute of Mining and Metallurgical Engineers in 1942. It shows that the hardenability of a steel is increased as much as 50% by as little as 0.003% boron, but beyond that spectroscopic amount the hardenability decreases.

In contrast to boron, the principal effect of nickel is to form a solid solution with the ferrite, and strengthen, harden and toughen this microconstituent. See Fig. 2, from Dr. Bain's book, reproduced below; it shows that a pure iron is about 70 hard on the Brinell scale; with 2% nickel the alloy is 100 hard, with 4% it is 120, and with 6% it is 140 (all figures are for metal in the annealed state).

Similarly Fig. 3, also from Bain's book, maps the effect of chromium on the tensile strength of air-cooled steels containing 0.20% carbon. Such an alloy steel with 1% chromium has a tensile strength of 75,000 psi.; with 2% chromium it is 105,000 psi.; with 3% chromium it is 160,000 psi.; with 4% chromium it is 195,000 psi.

The examples shown in Fig. 2 and 3 are of alloying elements that make alloy steels in the common, undisputed meaning of the words. Mr. Hibbard's definition therefore is correct as far as it goes, and the only addition necessary to make it more precise is to say that the modification and

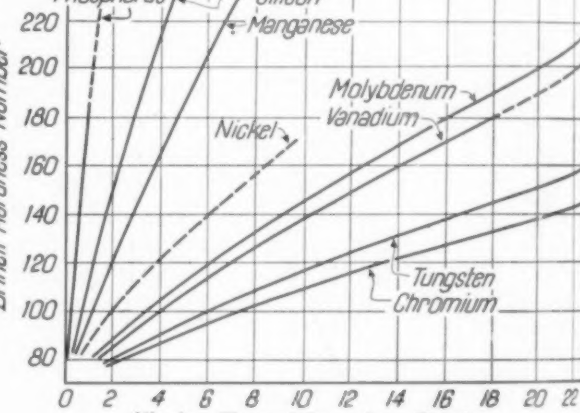


Fig. 2 (After Bain) — Estimated Hardening Effects of the Various Elements as Dissolved in Pure Iron

improvement vary directly with the amount of the alloy added. I would say then:

Alloy steel is steel that contains one or more metallic elements in sufficient amount to modify or improve substantially and positively some of its useful properties, and the amount of change in properties may be measured by the amount of element added.

Metallic elements of this sort can be called the true alloys, and it is perfectly logical for the consumer to specify their amount in the steel in order to give it the enhanced properties he desires. Specification and sale by analysis is easy and involves no ambiguity in the minds of purchaser or seller. A 3½% nickel steel has definite properties different from a 5% nickel

steel, and is adequately specified by the S.A.E. 2300 series.

So much for the true alloying metals in steel. Now contrast the above facts with the well-known effect of aluminum. Harry W. McQuaid said in his 1935 Campbell Memorial Lecture: "Actual steelmaking practice indicates that a certain definite minimum of aluminum is needed before anything much happens (in the way of controlling the grain size of quality steels), and beyond that amount the fine grain characteristics are obtained very rapidly." In other words, to exercise its beneficial effect only a little aluminum is needed; more is useless. (I pause to ask: "Would it appear reasonable for the purchaser to specify a minimum aluminum content by analysis, to assure himself that the desired grain size exists in the steel?")

We do not need to cite the relatively recent use of aluminum as an example of metals and quasi-metals that react in an entirely different way from the true alloys nickel, chromium, molybdenum and tungsten. The melter has always had "reaction alloys" for controlling the

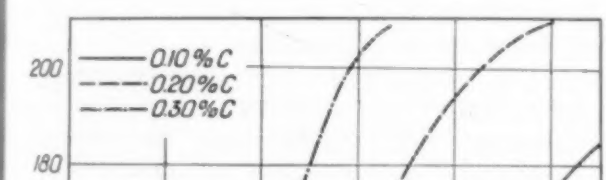


Fig. 3 — Cumulative Effect of Chromium on Hardenability of Steel Is Greatly Enhanced by a More Rapid Cooling From High Temperature. (Wright and Mumma)

deleterious effects of sulphur, phosphorus and nitrogen which inevitably get into his liquid steel. Bessemer's process was a failure until it was recognized that manganese was necessary for counteracting the bad effects of oxygen, sulphur and phosphorus in the molten metal. Silicon later was added intentionally as a deoxidizer (although willy-nilly it had always quieted crucible steel, enough being gained by reaction of hot metal with the crucible itself).

Furthermore, in distinction to the true alloys these "reaction alloys" have been the responsibility of the steelmaker rather than the consumer. Economy dictated their use; *enough* had to be added to counteract red shortness, or to improve the ingot's surface, or to control grain size; any excess over a safe margin was a waste. The *quantity* needed also would be variable, depending on the quality of the metal being refined, the process used, the pit practice and the rolling mill routine. "Reaction alloys", therefore, have been rightly regarded as mediums for the art of steelmaking; the effect of a moderate surplus in the metal delivered to the customer was quite minor, and consequently the customer generally has not been concerned with what reagents were used, or how much of them, as long as they exercised no deleterious influence on the steel or on his manipulations or uses of the metal.

In addition to manganese, silicon and aluminum, now come the new reaction agents or intensifiers containing such elements as boron, vanadium, zirconium and titanium which are active in some steels and steelmaking practices in as little as 1½ lb. per ton (0.07% gross — and far less of the potent portion), more frequently added in quantities of 4 lb. per ton of steel, but sometimes as much as 12 lb. They have such great effect that there is a temptation to class them as true alloys, but no familiar alloying metal has any measurable influence in such minute quantities. Likewise the facts that some steelmakers use more than others and get the same results, and that equivalent results can be achieved by several different chemical elements, bolster the belief that they are more properly classified as "reaction alloys". Again, the influence on the steel's properties is not proportional to the amount added. These facts exclude them from the category of alloy steels, and evidently bring them into Hibbard's third category; they are "alloy-treated steels" rather than alloy steels. With very little change (which we leave to the definition makers), Hibbard's definition of "alloy-treated" steels could be made most useful for present-day steelmaking practices, and I strongly suggest its revival.

Let me now put on record the fact that the properties achieved by the alloy treatment (in this sense) represent a very substantial improvement over the properties of a normal carbon steel or low alloy steel. The alloy-treated steels have four identifying characteristics:

1. They possess a new and high order of hardenability. For example, in his paper on "Special Addition Agent Steels" before the National Tractor Meeting of the S.A.E. (1943), R. B. Schenck cites a Y-1320 normal steel (manganese 1.50%; grain size 7½) whose J-40 hardenability* was 2.8, and the hardenability of the same steel with 4 lb. of reaction alloy per gross ton was 9.3. Or, put another way, a ½-in. round of the normal steel would harden through to the center in still oil, whereas a 1⅝-in. round of the alloy-treated steel will harden completely. (In recent technical discussions great emphasis has been placed on this improved hardenability of alloy-treated steel, although to my mind the next two characteristics are of even greater importance.)

2. They have very high ductility at high hardness. This is conveniently expressed as "P value"†. Using the same examples just quoted, the normal steel when oil quenched and drawn at 450° F. had 119,900 psi. ultimate, 60.7% reduction of area, and a P value of 96.8. The alloy-treated steel, heat treated identically, had 206,300 psi. ultimate, 56.6% reduction of area, and a P value of 111.0.

3. They generally have high Izod notched-bar tests after low tempering. This is more especially true of the medium carbon steels. Schenck quotes a normal GM1340-A steel (1.70% manganese, 7½ grain size) oil quenched and drawn at 450° F. whose Izod value was 5.5 ft-lb.; the alloy-treated portion of the same heat tested 21.8 ft-lb.

4. Alloy-treated steels behave normally on slow cooling; therefore they do not change the normalizing or annealing cycles by the purchaser.

This combination of characteristics in the treated steels indicates to me that we have hit upon a new way of doing something, and are not just achieving our old goals by varying the old methods, as by substituting manganese for nickel, or molybdenum for tungsten. This is an important distinction, and will probably be the most controversial statement in this article.

It is also to be remembered that, when treating a steel with an intensifier, there are several alternative ways of doing much the same thing — several different alloys available, and different routines in the refining operations. It ought to be evident that it is up to the steelmaker to decide *how* he wants to achieve the desired effects; if the effects are in the steel he ships (and their presence is easily demonstrable by tensile, notched bar and hardenability tests) the customer should have no cause to worry about the content of vanadium, boron, zirconium, titanium, aluminum, or other element in spectroscopic amounts and held in unknown microconstituents.

Final Recommendation

What is being recommended, therefore, in as emphatic words as I can muster, is that the carbon steels and the standard alloy steels be specified (as in the past) by their chemical analysis, but that no effort be made to specify a chemical analysis for the residual amounts of the reaction alloys when intensified steels are purchased. *Their* effects should be specified by specifying desired mechanical properties.

This represents no revolutionary change in commercial practices. Already it is commonplace for the purchaser to include other desired properties in addition to analysis, and for which the steelmaker receives extra compensation. Such special requirements and qualities, well known to the trade, already include macro-etch, inclusion count, grain size, specified microstructure, and guaranteed hardenability.

It is only a short extension of this practice to include that desirable combination of hardenability, ductility at high hardness levels, and toughness, which can most easily be achieved by the correct use of a reaction alloy.

I also strongly urge a revival of the classification "alloy-treated steels". The number of steels which properly belong in such a category is already large and will continue to grow. The control of nitrogen in steel through alloy treatment is not far distant and many other examples could be given.

Such a classification might well carry its own base extra to cover the cost of preparing the heat for treatment, together with whatever additional extras are justified depending upon the alloy used for treatment.

The important point is to avoid the compromises and confusion which result when attempting to place alloy-treated steels in a class to which they do not belong.

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*J-40 hardenability is the distance from the end of a Jominy end-quench specimen in sixteenths of an inch, to Rockwell C-40 hard. For a 0.20% carbon steel C-40 is about 8 points softer than the quenched surface.

†P value is $(T + 6R) \div 5$, where T is tensile strength in 1000 psi., and R is reduction of area in %.

Critical Points

By the Editor

TRUE TALK, by General MacArthur at the Japanese surrender: "Military alliance, balances of power, League of Nations, all in turn failed.... We have had our last chance. If we do not now devise some greater and more equitable system Armageddon will be at our door. The problem basically is theological and involves a spiritual recrudescence and improvement of human character that will synchronize with our almost matchless advance in science, art, literature and all material and cultural developments of the past two thousand years. It must be of the spirit if we are to save the flesh."

IN LIGHT of the above, re-examined and discarded some hard-won "Critical Points" having to do with munitions production, but salvaging the following hopeful impression of the things of the spirit that only can save us: "Out to Caldwell in Northern New Jersey to the propeller division of Curtiss-Wright, and got something of the spiritual lift of reading WALT WHITMAN's poems and breathing his unquenchable faith in America, ever growing greater and greater through the everyday work and life of millions of free men and women. For here, indeed, are literally thousands of young people bending their energies to the making of better and stronger steel blades to drive our aircraft to their destinations, and turning their minds toward the study and perfection of the magical mechanism packed into the hub that adjusts the blades so they bite deeper or shallower into the atmosphere at the pilot's will, and the even more wondrous devices, no bigger than a typewriter, that automatically adjust the blades to equalize the thrust from all the engines on a big ship. Magical machines, but no more wondrous than the spirit of young America that has devised them, the brains that understand them, and the skill that perfects their every detail!"

Wondrous men and machines

CHARMED by the rustic surroundings of Allegheny Ludlum's Watervliet mill, resplendent in autumn's foliage, yet found that even such a specialty plant as this has had a succession of problems, born of the necessity to make new and complicated steels. This is the prewar source of silcrome, the heat resisting steel discovered 30 years ago by P. A. E. ARMSTRONG, now the standard for automobile exhaust valves. What, then, more natural than this mill should turn to aero-engine valve steels when the civilian market for silcrome dried up? Easily said, but it involved some thorough-going changes in practice..... Four pounds of turnings, supposedly de-greased, come back for every five pounds of such bar steel shipped; scrap remelting without carbon pick-up immediately became a bug-bear, so turnings are put through a baby blast furnace, a short tower filled with roaring oil flame. Next, in the melting shop "wild" heats caused serious trouble until BILL NORRIS — an expert melter himself, graduated into Superintendent — decided to control the moisture in the lime flux; very simply, too, by barreling it, immediately after burning, in air-tight drums, kept closely sealed until actually needed.....Another problem developed in the forge shop, where 12,000-lb. steam hammers break down the ingot into blooms. The 14:14 Cr-Ni austenitic steel is so much more refractory than silcrome that the anvils started to "walk around". Eventually it was found they needed to be about 20% heavier — if the anvil is too heavy the hammer frame itself becomes unstable. The added weight can be a huge steel slab laid between timber mat and anvil casting, not necessarily anchored to either.....Now Ludlum's mill at Watervliet is rolling even more complex alloys for jet propulsion devices and these in turn are harder and harder at working temperatures. Four-inch blooms, for example, can be reduced no more than ⅛ in. per pass, and the safe temperature range is so narrow that reheatings are frequent. Surface defects cannot be scaled off; even the ingots of the high alloys must have their surfaces cleaned, and the billets are ground in two directions — first cross-wise with a coarse wheel to get to the bottom of folds or cracks, then lengthwise with a much finer wheel to remove previous grinding marks and all fins at the corners. A rough generalization is that the more heat resistant the alloy the earlier must attention be given to the surface defects.....Inspection of such valuable alloy is unusually severe. Billet ends

Successful remelting of high alloy scrap

Insuring surface & internal cleanliness

from first, middle and end of every heat of valve steels are submitted to the customer for surface inspection and chemical checks. If acceptable the billets are rolled to bars, and both sawed-off ends of every bar are deep-etched to reveal soundness and uniformity. Here's a place where the mill's inspectors must see with the same eyes as its customers'. Many requirements are met by hot rolled, shot blasted and pickled bars; some others need a surface so smooth that five polishing operations follow centerless grinding. Stock racks, inspection tables, and handling equipment in shipping room are of wood or rubber-covered steel, to prevent scratches and pick-up of iron particles.....Furnaces in both forge and heat treat shop (and all these alloys are heat treated, even if only for stress relief) are oil fired and operate under slight pressure. Oil and air valves are interlocked for practically complete combustion at all stages of turn-down; "radiomatic" control by improved radiation pyrometers automatically maintains temperatures within $\pm 10°$ of the set point.

Spent a fascinating afternoon in the Pittsfield plant of General Electric Co. with Messrs. Alimansky, Scoville and Hannon, and came away vainly thinking that I knew a lot about the "capacitors" they were making there in such numbers and varieties, but on more sober reflection realized that the matter is as mysterious as life itself.....If you want to know, capacitors or condensers are little packages that store lots of electricity. As made at Pittsfield they range in size from that of a tiny firecracker to a lady's traveling case. In the physics books studied by the generation now passing their prototype only is described; it is the Leyden jar invented by a Dutch professor 200 years ago when men were dangerously drawing lightning from the storm clouds and devising schemes for creating puny imitations thereof. The Leyden jar is of glass with metal linings, inside and out. If one lining is charged the other becomes charged oppositely, the glass insulation having something to do with it — but even that is still obscure. It is known that the capacitance (the amount of electricity stored) rises with the area of the metal and the thinness of the insulation; hence the content of a modern Leyden jar is a coil of aluminum foil interleaved by layers of tissue paper.....Aluminum is practically ideal for the purpose, although Hannon, the metallurgist, assured me that it is a highly specialized art to make this foil uniformly, say 0.0003 in. thick, wide enough without curled edges, and strong enough to unroll properly from the spool and re-roll into the condenser coil. Likewise the foil must be *clean* — clean even of the necessary lubricant on the rolling mills. General Electric alone buys several hundred tons of it annually.....The next step in the manufacture of capacitors is to put the metal-paper coils into tight containers, bake and evacuate them free of air and moisture, and then impregnate them with insulating liquid.....Metallurgical problems galore followed the wartime introduction of low-tin solders and substitution of terne plate for the tin plate cases. Since terminals must be soldered to the foil at low temperatures to prevent damage to the insulating paper, some of the new, higher-melting solders are useless. Hand soldering of the containers is also labor consuming, and the rejects due to leakers have warranted the installation of high frequency coils and fixtures for local heat just at the seam and nowhere else.....As the size of these capacitors increased, many mechanical and metallurgical problems entered, such as the necessity for water cooling, the discovery of a suitable substitute or improvement over the conventional mica insulation for high voltages, and the need for a sturdy metal-to-glass seal at the terminals. The latter is a clever design: A high nickel-iron alloy ferrule of the same coefficient of thermal expansion as the glass is cast into the glass. The bare flange on this ferrule sticks out all around, far enough so it can be soldered or brazed to the case with inductive heat, heat so quick and so localized it does not work over into the glass.....

Metal, solder, & other stuff in capacitors

Capacitor uses are amazingly widespread. They are essential units in all fluorescent lamps, in photo-flash lamps, in all radio, radar and television sending and receiving sets, in A-C motor starters and devices for correcting power factor, in electrostatic air filters, in "discharge welder" equipment for spot welding, in generators for high frequency heating and melting. As to their importance — did you know that power needed for many magnesium and aluminum plants was derived from systems already thought to be working at capacity, by installing thousands of capacitors at strategic points where existing consumers were drawing current at a low power factor? Sounds like lifting yourself with your own boot straps.

Pittsfield is also where General Electric makes transformers, and consequently the magnetic properties of silicon steel sheet used for laminated cores are under constant scrutiny by a group of physicists headed by Weston Morrill. The aim of the studies is to reduce the hysteresis

losses: the higher these losses the lower the efficiency of the transformer, the more of the electrical energy is wasted as heat, and the more elaborate and costly the necessary appurtenances for harmlessly radiating this heat. It has long since been discovered that a 4% silicon-iron sheet is several times as good as a plain carbon steel sheet, and extensive studies by many steel producers and transformer manufacturers have perfected the analysis and the steel refining, rolling

Lining up the crystals in silicon steel

and heat treating conditions so that modern silicon sheet has about 1/7 the hysteresis loss of ordinary steel when working under the conditions existing in an ordinary power transformer. This is for sheet whose crystalline line-up is helter-skelter, and such sheet is quite all right for elements of rotating apparatus. However it is not too good for *static* transformers, and one fruitful suggestion for improvement came from the knowledge that the cubic iron crystal has directionality — in other words, if *all* of the tiny crystals in the sheet could be ranged with their 100 axes in an optimum direction, the magnetic properties in that direction would be greatly improved. By cooperation between General Electric's and Allegheny Ludlum's metallurgists, the various production steps have been brought under control, so that sheet is now regularly produced with 90% of the crystals arranged within a 10° cone around the intended direction. In other words, these men can now tell a piece of steel how many crystals to grow, how big and in what direction.

To the Quincy (Mass.) shipbuilding yard of the Bethlehem Steel Co., and there found some intensive studies on the welding of big "rigid" structures, like hulls. Stresses induced in the plating of large sub-assemblies and even completed ships have been measured by cementing strain gage rosettes on both sides of the original plate at selected positions, trepanning out a 2½-in. disk at the spot after the plate is welded into the assembly, and then recording the changes in dimensions as indicated by the strain gages. These studies disclose two distinctive patterns of residual stresses in the plating of welded ships, depending on whether the plating is restrained or unrestrained during welding. One pattern is found in joints within sub-assemblies made while the plating is free to move to accommodate the shrinkage *transverse* to the weld; the residual stresses in that direction are consequently of a low order and are predominantly compressive. However, in a direction *parallel* to the weld there can be no movement of the cold and rigid plate to accommodate the longitudinal shrinkage in the hot and plastic weld metal as it cools. Consequently, the longitudinal welding stresses at and near the weld are of a high order, in fact of yield point magnitude, and average about 40,000 psi. tension. These strain gage studies also indicate that the magnitude of stress is unaffected by the welding technique. Long welds in a sub-assembly usually lie in a fore-and-aft direction

Innocuous weld stresses within sub-assemblies

and therefore the high tension stresses in welds in sub-assemblies also lie in a fore-and-aft direction of the ship. Now the reason why these high fore-and-aft stresses do not give immediate trouble as soon as some working loads are added is due to the presence of the mild compressive stresses athwartship, *transverse* to the weld. Welding thus sets up a bi-axial stress condition wherein the heavy tension *along* the seam (fore-and-aft) tends to stretch the weld metal, yet the moderate compression *across* the seam (athwartship) tends to push metal into the stretched region. Get the picture? Big stretch, little squeeze. Obviously this is a condition which makes for ductile action and promotes internal rearrangement in the metal — plastic yielding, in other words.....The situation is different when sub-assemblies are joined during the erection of the ship. Large sub-assemblies are stiff enough to afford considerable restraint, resulting in a stress pattern in the girth welds joining these sub-assemblies opposite to the pattern described above. The stresses parallel to the girth welds — that is, athwartship — are of yield point magnitude and average about 40,000 psi. because little movement takes place in the rigid sub-assemblies to accommodate shrinkage in the long welds. Fore-and-aft stresses at the junction between two sub-assemblies also result from the shrinkage transverse to the girth weld; due to restraint these stresses are

Dangerous weld stresses between sub-assemblies

tensile rather than compressive; their order of magnitude is also moderately high, being approximately 10,000 psi. in the vicinity of the weld. Therefore in these girth welds between sub-assemblies there may exist unfavorable zones of heavy tensile stress athwartship combined with moderate fore-and-aft tension stresses — that is, bi-axial tension. The normal working stresses of the ship can now be added to the moderate fore-and-aft erection stresses to fulfill a bi-axial stress condition in the girth welds that could induce a brittle failure. These conditions are a big stretch in two directions.....Bethlehem

Ship's Research Department, under supervision of Paul Ffield, has extended its work to scale models of hulls, as large as can be put into the stress-relieving furnaces. Working on the basis that the stress pattern described above is inherent in fusion welded joints, the department's aim has been to discover means whereby the highest stresses can be placed in most innocuous positions. It has already been found, for example, that the conventional welding sequence from the center of the ship, working outward in all directions, tends to throw tension stresses at the gunwales and bilges, and compression stresses in the axis. It appears logical to reverse the welding sequence and make erection joints from the outside toward the center. This should tend to confine the tension stresses to an innocuous zone near the neutral axis.....These all-too-brief notes about a stimulating visit must not close before giving special credit to Bethlehem Steel Co. The wartime fleet launched by its Shipbuilding Division has been singularly free from major cracks; nevertheless it is spending some real money and brains to determine the cause of the trouble that has been encountered by some of our all-welded ships.

Hardly believing my eyes, saw three small units, each about the size of a 500-hp. diesel engine, at Woodward Iron Co. near Birmingham, all that is necessary to "dry" the air for three 500-ton merchant furnaces — all, that is, except for three concrete chambers the size of hotel bedrooms, necessary air ducts and pipes for water and refrigerant, and a couple of small circulating pumps. The first of these units was installed in 1939 as an experiment to test the idea that high and variable summer humidity is the main reason why blast furnaces are more variable in operation and consume more coke in summer than in winter — a fact which will be contested by few experienced furnace men. Fred Osborne, Woodward's superintendent, said that a study of the firm's old records showed that an extra grain of moisture per cu.ft. of air in the blast would raise the coke consumption some 45 lb. per ton of iron produced, an amount that is close to the theoretical requirements for dissociating that much water into hydrogen and oxygen. Figures for the first 18 months of operation after the installation of the drying unit indicated a coke saving of 55 lb. per grain of moisture. Since, on the average the year 'round in Birmingham, 4 grains of moisture are removed to bring the outside air down to saturation at 40° F., 220 lb. of coke is saved, or 8% on the 2700 lb. formerly needed to smelt the rather low grade ore from Red Mountain nearby. Small wonder that the other two furnaces were promptly equipped.....

Less coke in summer than in winter

Metallurgically the advantage rests in uniformity of product. For example — at one time a cooler was down for 8 hr. on a rainy summer's day; the iron from that furnace went from a 3.25% silicon foundry grade to basic (under 1.0% silicon) on one cast, but right back again when the drier resumed operation.....This system of Carrier Corp. does not attempt to *dry* the air; it delivers air at a constant humidity represented by saturation at 40° F. — that is, a little less than 3 grains H_2O per cu.ft. The three main units at Woodward may be viewed as large editions of the freezing unit in a household refrigerator, wherein an organic chemical, while evaporating, absorbs heat in cooling the box — except that in this case what is cooled is not the family's butter and meat but a flow of water through a nest of pipes. The gaseous chemical is then compressed below its critical pressure, cooled and liquefied in a tubular heat interchanger, and is ready for another trip through the closed circuit. We therefore have two flows of water coming from the refrigerating unit in the power house — one is warmed water carrying away the heat from the liquefying refrigerant (and this water is sent direct to the boiler house pond), and the other is a recirculating supply of chilled water at 38° F., cooled by the evaporating refrigerant. This cold water, well above the freezing point (where frost gives no end of trouble) enters the air chambers as a multitude of fine sprays against the air being sucked through to the blowing engines. Enough cold water is circulated in this way between the refrigerating unit and the air chamber to cool all the intake air to 40° F., and this cold air then drops out its cooling spray and the excess condensed moisture against a tier of baffle plates, and is on its way to the blowing engines.....Costs are little more than interest and amortization on the equipment. The power used is almost all saved at the blowing engines, which now compress a smaller volume of cold air (although of the same weight). Numerous regulators for temperature and flow make the equipment almost automatic. Osborne says refrigeration of the blast is the last of the major improvements reaching back for a decade, which include a drive for coke with low ash, properly sized and of better structure, and for sized and selected ore — all responsible for Woodward's ability to make more and better iron at lower costs.

Dried (not dry) blast

NICKEL

gives a bandsaw *BITE!*

...this specialty steel (a high-carbon grade) toughened by Nickel

Built for tough jobs, this bandsaw is .80 carbon steel fortified with 2.25 to 2.50% Nickel.

The maker . . . E. C. Atkins and Company of Indianapolis, Indiana . . . specifies Nickel to secure the reliable performance assured by the special mechanical properties developed by high-carbon Nickel alloy steel.

In addition to imparting ability to withstand repeated flexure, Nickel improves wear resistance, handling characteristics in fabrication and response to heat treatment.

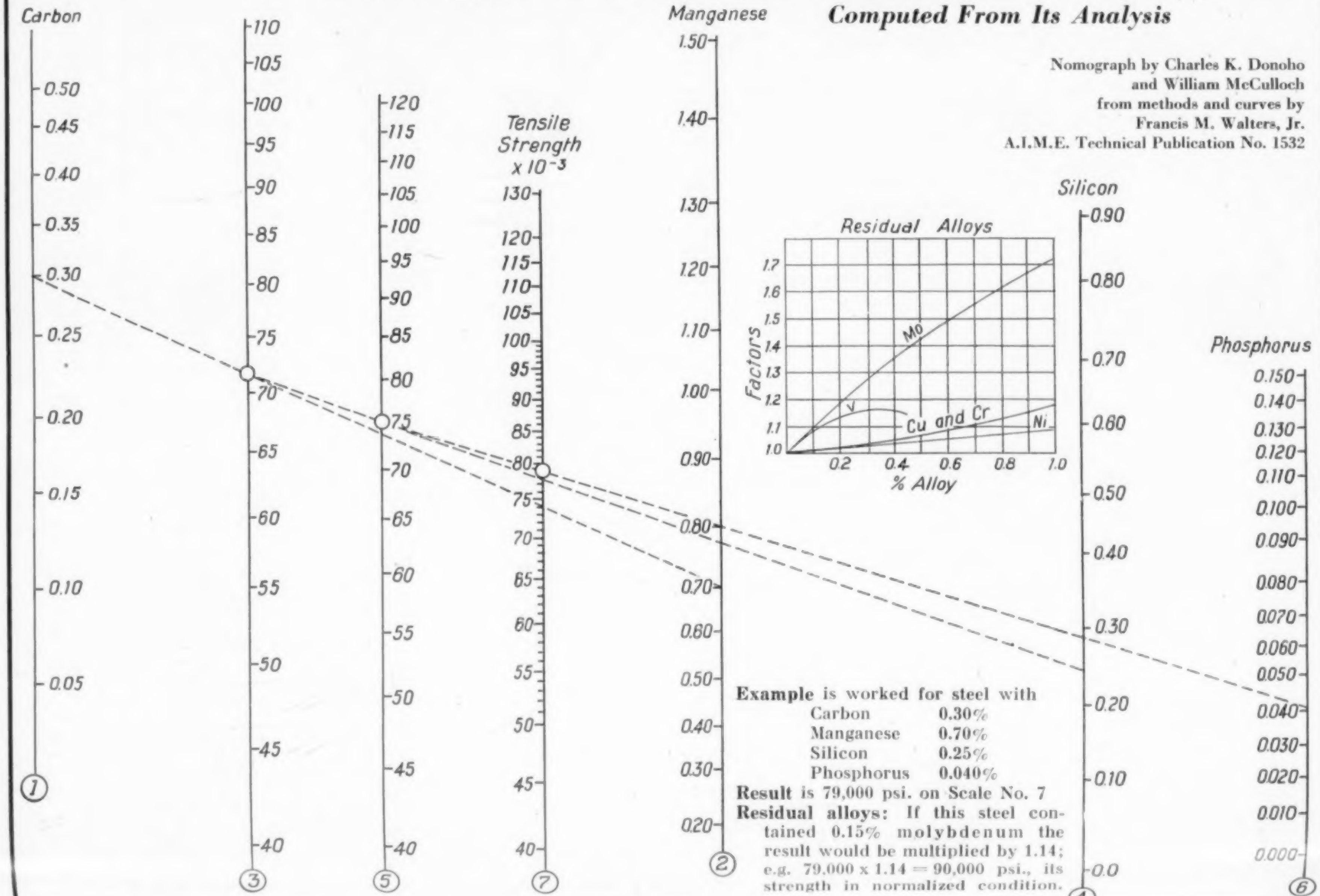
Consult us on its use in your products or equipment. Write us today.

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.

Strength of Normalized Steel

Computed From Its Analysis

Nomograph by Charles K. Donoho
and William McCulloch
from methods and curves by
Francis M. Walters, Jr.
A.I.M.E. Technical Publication No. 1532



Example is worked for steel with

Carbon	0.30%
Manganese	0.70%
Silicon	0.25%
Phosphorus	0.040%

Result is 79,000 psi. on Scale No. 7

Residual alloys: If this steel contained 0.15% molybdenum the result would be multiplied by 1.14; e.g. 79,000 x 1.14 = 90,000 psi., its strength in normalized condition.

The Ouija Bar and the Fancy Slip Stick

By D. Carb
Pittsburgh

W HY I EVER get mixed up with the Metals is still not quite clear, unless it's because during my youth the old man is always hollering about crystallization, at the same time he's hammering no end and pulling a rear axle out of the Chevvy. Now my parent is not quite consistent, in my opinion, as he is also always bragging about the swell butcher knife he makes from an old broken spring leaf and I remind him that at the time the spring breaks his discourse is extraordinarily profane on the crystals et al so how come it makes such a good knife? The only result of my observation is a cut in my allowance. I often suspect that my present affiliations are the result of this incident which unconsciously gives me a desire to know something about the stuff.

In the University I later attend, I major in Football with some liberal arts on the side. I play a bang-up game and they are plenty liberal with the Arts so we get along fine and in due course I'm out.

About a month later I'm offered a job in a Forge shop. They want me to work on a hammer but I point out I only went to school so as not to have to bend my back eight hours a day the rest of my life. They seem somewhat dubious concerning my formal education so I ask them if they remember last year's event with State when a certain guy runs 90 yd. in the last 30 sec. to pull the game out of the fire? They then concede the point but aren't particularly impressed. However they say OK I can work in the labratory, so I sign up right away with CIO as that labratory sounds pretty good, a decision which as you will see I later come to regret.

I'm slower than a furnace full of cold steel for awhile. These people I'm working with talk a language all their own and I start to wish that I had studied pharmacy or something but after awhile I start to catch on.

Now my Superior is usually a Man not given to motives ulterior so when he calls me in one day and asks what I know about hardenability I don't smell the rat. Anyway I answer right quick that I've been running the Rockwell for two whole weeks and can twist the dial and record the numbers as well as the next guy. I immediately sense maybe that's the wrong answer as he gets up and sits down twice about as fast as our trip hammers, mumbles something about War and then tells me never mind.

The next afternoon as I'm running the hardness tester using the sharp point he keeps walking by watching me all the while so I figure he's sizing me up and I don't even leave for coffee. This works fine and I'm certain the proper impression is made when the next day he shows a lot of interest in reading my records. In fact he asks that everybody watch me closely and read my figures which is quite a distinction.

But to get back to hardenability, I'm finally put in charge of all the little round bars which are about four inches long to which we do a lot of things. You'd never believe the trouble we go to working on these bars. What's so discouraging is that after we get them all machined and ground and make all the little marks, which have to be just so far apart, we pile them up in a corner and let them rust. Anyway for the next few weeks I'm rushing around like I got a hot cinder down my back seeing that the pieces are cut, forged, machined, and heated in the round box and then stuck one at a time in the hole over the water spout. It seems like a lot of nonsense repeating the same thing over and over again and I finally discover to my amazement that all they want to know is where the hand on the dial stops when they put the bars under the hardness tester. I'm convinced by now that there must be an easier way, and further I can't understand what the stopping place on the dial has to do with the big chunk of steel we put under the hammer and,

particularly, what relation this rat race has to do with the parts we make which aren't little round bars at all.

The longer I try to figure this out the more confused I get and I reach the conclusion that the whole set-up must be due to the current political Party in power who gets me so mixed up in other things. One day when I'm waiting for the furnace to get hot I up and asks the Super if he wants me to take this silly situation up with our Ward Boss, a good friend, who has many times helped me out of other Bureaucratic restrictions. Starting real gentle and quiet-like the Chief says this routine isn't a government order at all. In fact it's his own idea to use this system which some smart guy named Jominy cooks up originally — his voice getting louder as he ends the sentence.

He somehow knows I'm skeptical, just like he can tell every time if the machine shop forgets to keep that white oil running on the Jominy bars when we grind them. Before I can stop him he's giving me a lecture on why I'm working with these bars and believe it or not, he talks for an hour. If what he says is true this guy Jominy starts where Ouija leaves off. I learn that the outfits that make the steel finesse a whole heat if the Jominy bars aren't hard enough. In fact they sometimes have to be just *so* hard, at maybe one single position on the bar. That's slicing it pretty thin and the whole thing, as far as I'm concerned, borders on the occult. I make it a point to check this tale with the rest of the fellows individually around the place and all their stories jibe. Finally I'm convinced after they show me prints of a lot of parts where in writing it says J-50 @ $\frac{5}{16}''$ which weird as it may sound is one of the most important parts of the spec, from the way they insist on it.

The boys in the lab and the plant see I'm interested and one night we all stay for a little meeting and the Brain Trust is invited and everybody lets his hair down. It blows hot and heavy for a couple of hours and here's the way I get this Jominy business:

The brain trust says that every position on the bar has a very definite cooling rate and cooling rate determines hardness. That's why I have to be so precise in running the test. Also chemistry must be OK. Further I'm informed that although hardenability depends on the amounts of chemical elements in the steel they are more concerned about the hardness of the little Jominy bar at various positions than they are about the exact chemistry of the big heat of steel it came from. This sounds contradictory but I don't get to dwell on it long as they keep going with something about grain size which I miss entirely.

Sticking a hot piece of steel in an oil tank always appeared to me to be a clean cut simple procedure about which there could not be much controversy. Well brother, these guys really complicate things and we get so involved with this process that I'm almost ready to resign. However one thing seems to be apparent from all this and that is that the depth of hardness of a heat treated part (and the brain trust go to great lengths to emphasize *depth*) can be directly hooked-up to this little Jominy bar so it is very, very important.

One of the fair haired boys almost breaks up the bull session when he says tempered Jominys are what we really ought to be running. I miss the next few minutes as I am turning over in my mind these amazing facts which start to explain many of my past sad experiences. Most of the evening everybody has been friendly even in the heat of argument. Things are starting to slow down when all at once the place fairly explodes with gesticulating comment. Even the Super a man of much composure waxes nigh unto irrational. I get out of that meeting in a hurry to meet my cup-cake and never hear the finish but I seem to recall that about the time things blew up we were talking about hardenability elements when somebody said something about Moron. Who called who, I never do find out but the next day everybody seems as friendly as ever. Funny about these scientific Guys.

After this session I see the light and painstakingly carry on watching that everything runs smoothly and I get a lot of sheets with hardness readings on them. Once in a while the Boss looks at one of the sheets and gets excited and we have to tell the shop to lay off a certain lot of steel. This invariably awards us with a call from one of those Fellows from out of town who rides the trains and drinks beer and argues with the super for a living.

Yesterday this fellow is in and after we settle the current trouble which is that three of our Bars don't quite make the proper hardness, the chief starts talking about the new part somebody needs quick and if we can use a bunch of squares sitting out in the field. I figure the old Man is just testing this guy as we looked over our figures this morning on the stuff and the boss said go ahead.

The poor unsuspecting visitor looks at the drawings of the part, and the chemistry of our old steel squares, asks us who's going to get the parts and how they treat them? The boss answers all the questions and is sitting back with a look on his face like the time he takes my bet on my

Alma mater that cost me plenty. The fellow in the double-breasted produces a gadget he calls a slide rule and starts playing with it. Next thing we know he's looking at a long strip of paper with a lot of lines on it and all at once he says sure we can use the bars. The Super closes his eyes and smiles and says why is the other one so certain.

I hate to see a good guy mouse-trapped like that and I'm feeling sorry. The visitor says as how their company made the heat so it's S_5O_6 and further it will give a Rockwell of 45 at $\frac{5}{16}$" which will easily make the part. The boss shifts forward and asks how come he knows about 45 at $\frac{5}{16}$" all the time looking at me like I spilled something. (Now I worked half the night before getting out the Jominy because we didn't know if we could use the stuff but I sure as hell didn't say a word.) The visitor says something about D I, whoever that is, and shoves the odd rule at the Chief, and the two of them start sliding it. Finally they start writing down figures and so help me they come out with practically the same dope it takes me half a night to collect.

It's easy to see the Chief is impressed, in fact he makes the other guy manipulate the Gadget for almost an hour. The session finally breaks up with the tall one promising to send us one of those calculating outfits and the chief muttering something about *his* sweating blood for a college degree. I stay a little late and look over the curves they draw compared with the ones I make from putting the bars through the furnace and come to the conclusion that I chose the wrong job after all.

All the way back through the shop on the way to the parking lot I'm thinking if it weren't for the question of post-war employment I'd get the burner to cut up that Jominy Jig the day we get the fancy slip stick. Also I use the old bean and figure that then they'd have to have a lot of chemical compositions and that would mean an annex on the chem lab and Ma sure didn't raise her Son to be an analyst.

Correspondence

Direction of Notch in Impact Tests on Plate Steel

MUNHALL, PA.

To the Readers of METAL PROGRESS:

The article by G. F. Comstock on "Mechanical Properties and Weldability of High Strength Plate" in the March 1945 issue of *Metal Progress* was of considerable interest to us as we have just completed a study involving some impact tests on plate material of the same type. The study included a number of heats and a number of different plates from the various heats. The tests included material as-rolled and after normalizing at 1600° F.

Unfortunately, the results of our tests did not substantiate the high energy absorption values obtained by Mr. Comstock. His values ran as high as 206 ft-lb. at —30° F., 180 at 32° F., and 199 at 70° F. When our values (each the average of three or more tests) are plotted we find them to fall within the limits of 3 and 40 ft-lb. at –25° C. (–13° F.), 5 and 110 ft-lb. at 0° C., and 10 and 110 ft-lb. at 27° C. (80° F.).

Perhaps the high impact values obtained by Mr. Comstock may be explained by our experiences with this type of steel.

In order to expedite the preparation of the impact specimens the notches for a group of parallel specimens were produced by milling the notch parallel to the rolled surface and subsequently machining the individual specimens from the larger piece. Mechanically the procedure was satisfactory, but the impact values obtained ran as high as 207 ft-lb.; some specimens bent without breaking, and others known to be brittle at the temperature of the test gave erratic and abnormally high results. Additional tests from the same plate were prepared from sections adjacent to the previous tests. This time, however, the specimens were prepared individually with notches milled *normal* to the rolled surface. When these specimens were tested the impact values obtained were "normal" and within the limits noted above.

The reason for this abnormal behavior of the material notched parallel to the rolled surface was readily apparent. Some of the specimens were badly laminated and the notches often

terminated at or near a plane of lamination. Under these conditions the stress concentrating effect of the notch was completely nullified and the specimen reacted in simple bending.

The rolling of steel plate quite naturally develops a fibrous condition with planes of varying mechanical properties parallel to the rolled surfaces. Thus it is logical, regardless of whether the material is clean and homogeneous, or badly segregated and laminated, to place the Charpy notch *perpendicular* to the plane of rolling and thus average out the effects of surface-to-surface variations within the plate.

W. R. ANGELL and M. R. GROSS
Materials Engineer — Associate Metallurgist
U. S. Navy Metals Laboratory

Mr. Comstock Replies

The steels in my experimental program were all notched in the same way, namely, parallel to the surface of the plate, and consequently the results published should show the comparative order of merit of the steels in this test, when so made. It appeared logical, also, to notch the rolled surface of the plate because this simulated the conditions to be expected in service. It is hard to imagine a notch of any importance that might be produced in welding or fabrication or by accident, that could be other than parallel to the surface.

Unfortunately, the "impact" test is not yet standardized. Undoubtedly it would be difficult to standardize between laboratories because of slight differences in the form of the notch. For that reason the results are of most importance to a single laboratory when comparing one steel against another, and then only when numerous circumstances are held under constant control.

We have, however, repeated our tests on certain of the plates, cutting the notches perpendicular to the surface, and find that it does indeed make a surprising difference. These re-tests gave results as follows:

STEEL No.	NOTCH PERPENDICULAR TO SURFACE			OLD RESULTS; FT-LB.
	HEAT TREATMENT	TEMPERATURE OF TEST	IMPACT RESISTANCE FT-LB.	
1	As rolled	32° F.	51; 30; 29	176; 175
1	Normalized, 1600° F.	−30° F.	35; 36; 47	206; 198
3	As rolled	32° F.	53; 59; 60	180; 169
4	Normalized, 1600° F.	−30° F.	12; 17; 17	135; 165
5	As rolled	70° F.	69; 68; 76	154; 155
8	As rolled	70° F.	40; 47; 56	146; 153
9	As rolled	−30° F.	20; 25; 9	124; 151
10	As rolled	70° F.	48; 66; 59	146; 158

The ratios of average impact values with notch perpendicular to plate surface to those with notch parallel to surface (as reported in *Metal Progress*) are as follows:

Tests at 70° F.	0.32 to 0.44
Tests at 32° F.	0.21 to 0.32
Tests at −30° F.	0.10 to 0.19

These results show that the effect of temperature on the impact test results was reduced by our use of notches parallel to the surface of the plate. It seems probable also that the higher notch sensitivity of certain samples, such as numbers 4, 7, 12, and 13, may have been exaggerated by our method of testing as compared with yours. The large difference between the results obtained with the two methods of notching is quite surprising, as our samples did not seem to be badly laminated or seamy.

Choice of Acceptance Tests as Exemplified by Anti-Friction Alloys

PARIS, FRANCE

To the Readers of METAL PROGRESS:

Tests used to select metallic materials for a specific application (acceptance tests) can be based on two methods of attack:

1. A theoretical conception can be formed of the mechanical actions to which the material is submitted in service, and the tests which will insure its resistance to these actions can be deduced therefrom.

Without disparaging the theories of elasticity or strength of materials, or the new technique of stress analysis, large errors are sometimes involved — later to be rectified by experience — by using various direct methods of stress determination in structural or machine parts. I refer to such methods of testing as photo-elasticity, "stress-coat" lacquers, or strain gages. Mathematical formulas cannot adequately predict, even in parts of simple form, the influence of a series of factors that are difficult to analyze and measure, such as shock, vibration, inertia, interference of stresses between different materials, and surface effects such as corrosion and abrasion.

2. On the other hand, an objective and experimental method can be adopted which consists of examining and analyzing the manner in which the parts deteriorated in service, observing particularly the characteristics of the fracture when

rupture occurs. A method of testing can then be adopted which reproduces the phenomena and characteristics thus determined.

For example, if the piece fails by brittle fracture (as in the case of railway tires), the tensile test could be adopted if it reproduced the type and characteristics of the fractures observed. If, however, a fatigue failure occurred (as in the case of aircraft engine crankshafts), the endurance test would be favored. Obviously, the classical tensile, hardness, shock, and similar tests should not be invariably and rigidly prescribed, as is so often done, regardless of the nature of the metal or the part.

A typical recent example is furnished by M. Dannenmüller's analyses of tests for appraising anti-friction alloys for thin-wall babbitt bearings within steel or bronze bushings or shells. These alloys have ordinarily been judged by the classical hardness, compression and sometimes tensile and shock tests. Actually, however, observations show that operational failure is produced by the following mechanisms:

1. Seizure may result from poor lubrication or imperfect machining of the rubbing surfaces. Direct contact of metals produces high local heat, which either fuses the bearing or causes momentary welding to the shaft. Such failure is a mechanical trouble and the metal of the bearing is not the cause; all that can be required of the latter is that it melt in such a manner as to limit the damage by leaving the shaft intact. The anti-friction metal must be sacrificed in order to save the mechanical part. Fusibility of the alloy is therefore a property to be considered.

2. Seizure may result from the shaft and the bearing being off center, either as a result of imperfect mounting or machining, or of relative displacement of the supports of the journal box. Gripping of the shaft, high stress localization, and failure by the same mechanism as outlined above then ensues if the plasticity of the metal (its tendency to deform under constant load) does not permit this load to be spread over a large surface by flow of the metal. This flow of the metal should stop — or at least become stabilized at an insignificant rate — as soon as the pressure is again reduced.

3. Fissures and fragmentation in mosaic patterns may appear in the anti-friction layer so that it eventually becomes separated from the support or the metallic bushing (generally steel). This is a result of alternating bending to which the assembly of bushing and babbitt is submitted. Experience has shown that this is not caused by shock but by bending. The phenomenon has been reproduced by the alternating bend test or fatigue test on bands of steel babbitted with a thin layer of anti-friction metal. The latter operates under constant deformation imposed by its support; it should, therefore, possess a low modulus of elasticity.

The properties and control tests may now be enumerated as follows:

1. Sufficient fusibility, determined by the choice of the composition of the alloy.

2. The proper degree of plasticity, determined by flow tests.

3. Low modulus of elasticity, determined by precise tension or bending tests.

Other properties which are generally considered to be of great importance, such as thermal conductivity and coefficient of friction, appear to play only a secondary role.

Thus, a careful and critical analysis of the types of failure affecting the life of bearings has led to the adoption of entirely different tests from those formerly used to appraise and control anti-friction alloys.

Albert M. Portevin
Editor
Revue de Métallurgie

A Core of Gentility

Washington, D. C.

To the Readers of Metal Progress:

Here is proof that interesting metallographic oddities can be found in photomacrographs as well as photomicrographs. People occasionally get into hot water, but it is supposed they shortly

may escape from this predicament. However, here is photographic evidence of an elderly lady who was exposed to hot water ($1\frac{1}{4}$-in. pipe) for a period of eight years. She obviously has been able to maintain her dignity and coiffure despite her corrosive surroundings.

Gerrit De Vries
Assistant Metallurgist
National Bureau of Standards

Maximum Carbon in Carburized Cases

CINCINNATI, OHIO

To the Readers of METAL PROGRESS:

Recently there has been discussion in *Metal Progress* relating to maximum carbon in carburized cases. Consideration has been given to this problem by Floyd E. Harris, April 1944, page 683, and Sidney Breitbart, June 1945, page 1121.

Without going into the subject at too great length there seems to be no reason why the maximum carbon should be limited by the Ac_{cm} line — in fact, there is reason to believe otherwise. It is our impression that this problem was settled long ago. Georges Charpy in *Comptes Rendus* for 1903 found that in carburizing a 3-mm. diameter piece of steel at 1000° C. he obtained 8.32% carbon (7.66% as graphite) after 64 hr. in coal gas and 9.27% carbon (8.27% as graphite) after 36 hr. in pure CO gas.

	No. I	No. II	No. III	No. IV	No. V
Compacting pressure, psi.	23,000	23,000	9,000	23,000	138,000
Time at 1700° F.	20 min.	20 min.	24 hr.	24 hr.	24 hr.
Carburizing media	Hardwood charcoal only	Hardwood charcoal +10% Na_2CO_3	Hardwood charcoal +10% Na_2CO_2	Hardwood charcoal +10% Na_2CO_3	Hardwood charcoal +10% Na_2CO_3
Carbon added	1.6%	6.3%	15%	11.2%	3.1%
Form of carbon (judged by metallographic examination)	Carbide of iron	Mostly carbide of iron	Mostly graphite + some carbide of iron	Mostly graphite + some carbide of iron	Carbide of iron + graphite

For some time now in our metallurgical laboratories at the University of Cincinnati the undersigned and his associates R. O. MCDUFFIE and E. E. STANSBURY have been conducting experiments on the simultaneous sintering and carburizing of compacts of pure iron powder ("iron carbonyl L") with an additional hydrogen reduction at 50° F. The samples were ¼-in. disks about 0.040 in. thick. They were pack carburized at 1700° F. Results of five typical tests are given in the table.

These are just a few results in a fairly extensive study. Incidentally, we are not planning to rely on identification of kinds of carbide or of graphite by means of the microscope alone.

It is difficult in view of this evidence for us to consider the Ac_{cm} line as a limit. Consider, 6.3% average carbon in 20 min. at 1700° F.!

JOHN F. KAHLES
Assistant Professor
Metallurgical Engineering
University of Cincinnati

Arc Welding of Rail Steel

WATERTOWN, MASS.

To the Readers of METAL PROGRESS:

The article "Arc Welding of Rail Steel" by Messrs. Haynes, Graft and Spencer of Armour Research Foundation in *Metal Progress* for May 1945 is particularly interesting for its emphasis on the heat input as an important factor in making a satisfactory weld. It is regretted, however, that the authors did not also include data on size of their electrodes, together with either rate of arc travel or current and voltage, so that the reader could better appreciate the actual welding conditions when interpreting the results.

The figure of 11,000 joules per in. of bead on ⅛-in. material, given as an optimum value for heat input on the basis of base metal thickness, is a somewhat novel concept. On such a basis we would need 88,000 joules per in. for a 1-in. section of this material, and higher values for heavier sections. (Whether the cooling rate should be controlled by regulating heat input or by preheating is determined by whichever is the simpler to apply and most dependable in practice.)

In the third statement of the conclusions given on page 915 ("Rail steel, and similar high carbon steels of the section weights discussed in this paper, can be welded with high heat input rates and with a good degree of success without the precaution of preheat and stress relief") the phrase *"of the section weights discussed in this paper"* should be emphasized.

WILLIAM L. WARNER
Senior Welding Engineer
Watertown Arsenal

The Authors Reply

The size of electrodes should have been mentioned. ⅛-in. welding rods were used on sections ⅛ in. thick, $\frac{5}{32}$-in. welding rods were used on sections ¼ and ⅜ in. thick, and ⅛ or $\frac{5}{32}$-in. welding rods were used on sections $\frac{3}{16}$ in. thick. The size of rod used is determined, not from heat input required, but from the convenience of the welder, to enable him to get a good physical weld with proper penetration and bead contour.

The currents used were somewhere near the middle of the range recommended by the manu-

facturer of the particular rod being used. Here again, it is necessary to choose the current in such a way that the heat input requirements are met and, at the same time, the rate of travel of the rod is such as to produce a good physical weld with proper penetration into the base metal. Too low a current would probably result in poor penetration and slag inclusion in the weld deposit; if too high a current is used the weld deposit would probably contain gas pockets.

The heat input mentioned in the article is both a minimum and optimum value. However, it is often possible to depart from these conditions and still get good welds. If the heat input is less than the minimum suggested, martensitic hardening is almost sure to result and it is almost impossible to get a good weld. However, it is possible to exceed the heat input suggested and get very good welds. We often exceeded the optimum heat input suggested in the article without obtaining excessively large grains or bothersome internal stresses.

We do not argue that preheating might not be a highly satisfactory way to produce good welds in rail steel or metal with a similar chemical composition. However, in many instances, it is an economic problem and if welds can be produced without preheating, there is usually a marked saving in expense.

In all probability, the difficulty of putting in sufficient heat to produce good welds without preheating will increase with increasing section thickness. However, our experience indicates that sections thicker than the ones reported in the article can be welded very satisfactory using the technique described.

Stress-Corrosion Cracking of 18-8

SHEFFIELD, ENGLAND

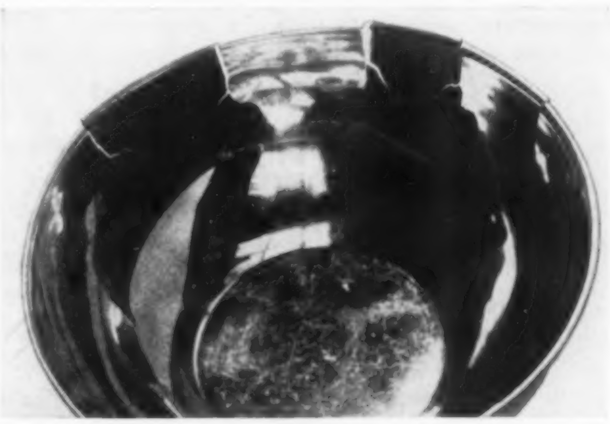
To the Readers of METAL PROGRESS:

The combined effects of stress and corrosion upon metals are of considerable importance in industry, and have been studied by many different investigators. Probably more attention has been given in the past to conditions where stresses were fluctuating or alternating rather than steady, and one need only refer to the extensive researches carried out on corrosion fatigue by McAdam in America and by Gough and his collaborators in England to realize the complexity of this particular part of the subject.

A study of technical literature would suggest that, until recently, less attention has been given to the combined effects of *steady* stress and corrosion. Actually, however, a considerable amount of work on this subject has been carried out in certain laboratories over a period of some years. The symposium arranged by A.I.M.E. and A.S.T.M. and held in Philadelphia in November of last year* on "Stress-Corrosion Cracking", as it has been termed, has served to focus attention on the fact that various metals and alloys in common use, including stainless steels of various types, are liable to crack if they are subjected simultaneously to steady stress — either externally applied, or internal and resulting from prior cold working or heat treatment operations — and to the attack of certain corrodents.

Much of the recently published data has referred to laboratory tests in which stainless steels, suitably stressed, have been exposed to rather severe corrosive conditions, the idea being to obtain some quick indication of the steel's probable behavior when subjected for long periods under stress to milder forms of corrosion.

Some examples of failure under working conditions have also been recorded and they have indicated that stress-corrosion cracking of austenitic stainless steels can occur in environments which can only be considered as mildly corrosive. It may be interesting therefore to quote an example, which occurred some years ago and is illustrated in the accompanying photograph, of cracking in severely strained stainless steel of the 18-8 type where the corrosive environment consisted of the atmosphere in a city hospital. The hospital bowl shown in the photograph was drawn from polished sheet and the beaded edge then turned over. No intermediate or final softening was given — probably in order to save the expense of descaling and repolishing — and consequently the final product was in a drastically cold worked condition, especially at the



Hospital Bowl of 18-8, Failed by Stress-Corrosion

*Reported in *Metal Progress* for January 1945, page 75.

beaded edge. The bowl cracked in the manner shown after it had been in use for a short time, and other similar bowls cracked while held in stock — standing unused on the shelf.

Whether such cracking is due entirely to internal stress and therefore could occur in the complete absence of corrosion is a question to which an answer is not yet forthcoming. It seems very probable however that its onset may be accelerated by certain types of corrosive attack.

In the apparently somewhat analogous "season cracking" of brass, a solution of mercurous nitrate has proved invaluable in showing in a few minutes whether a given sample is susceptible to this serious type of failure or not. No equally efficient reagent seems yet to have been discovered for the austenitic stainless steels, but tests carried out in Brown Bayley's research laboratory some 12 or 13 years ago indicated that immersion for 24 hr. in a 5 or 6% solution (by volume) of concentrated hydrochloric acid in water at atmosphere temperature appeared to give a fairly satisfactory indication. Possibly the boiling concentrated solution of magnesium chloride recently suggested by Scheil may be still more effective. Tests with the hydrochloric acid reagent suggested that cracking might occur in cold rolled material having a tensile strength of about 200,000 psi. or more; on the other hand no evidence of cracking with this reagent was obtained when tensile strength did not exceed 180,000 psi., even when such material was also subjected to a certain amount of externally applied stress while immersed in the test liquor.

These results are of interest in several ways. When read in conjunction with recent data relating to severer corrosive environments — and, probably, lower stresses — they suggest that the subject of stress-corrosion cracking is probably a very complex one.

From a practical aspect, the failure of the bowls indicates the wisdom of the general practice in industry of softening deep drawn articles in 18-8 steels as soon as possible after drawing; it also shows the danger which may result from using 18-8 in the heavily cold worked condition for such purposes as in the structure of aircraft where any failure by cracking would have most serious consequences.

In the latter connection it may be noted that, in Britain, the tensile strength of cold rolled 18-8 sheet or strip used for aircraft construction is limited by specification to a maximum of 70 long tons per sq. in. (157,000 psi.).

J. H. G. Monypenny
Chief Metallurgist
Brown Bayley's Steel Works, Ltd.

Pit Corrosion of Magnesium Alloy Castings

Hatfield, England

To the Readers of Metal Progress:

I have read with interest of Mr. Miller's experiences with magnesium castings as given on p. 752 of the October 1944 issue of *Metal Progress*. My own experience is that every corrosion problem is one alone; each requires personal investigation on the spot by a competent investigator before intelligent comments can be passed.

Atmospheric conditions here at Hatfield are described by us as "rural" since there is virtually no industrial polution. Under these conditions we have had small magnesium-base alloy castings on atmospheric exposure test for 4 years. The nominal composition of these castings is 8.0% aluminum, 0.4% zinc, 0.3% manganese. They are supplied as castings to British specification DTD.59.A, whose impurity limits are rather higher than those stipulated in U. S. Army and Navy specification AN-QQ-M-56.

The castings in question have been continuously exposed to the natural elements. Included in the series is a casting which has been treated by the British Royal Aircraft Establishment "half-hot chromate process" only. As the excellent condition of this casting may be of interest a photograph is reproduced.

As regards storage: It is desirable that such parts be kept in a clean dry place. If storage conditions are not good, then the application of a suitable organic protective may be worth while.

G. W. Weeks
Aircraft Division Metallurgist
The de Havilland Aircraft Co., Ltd.

Good Condition of Magnesium Casting Protected by "Half-Hot Chromate Process" Only, After 48 Months' Exposure in Rural Atmosphere. Actual size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Personals

Joe Viall will be district manager of the newly opened Milwaukee offices of Chicago Steel Service Co.

Waldemar Naujoks, chief engineer, Steel Improvement & Forge Co., has been appointed a member of the Technical Committee of the Drop Forging Association, Cleveland.

Stephen F. Urban has resigned from Carnegie-Illinois Steel Corp., Chicago, to become director of research for the Titanium Alloy Mfg. Co., Niagara Falls, N. Y.

Paul S. Kingsley, formerly with Wright Aeronautical Corp., is now metallurgist for General Electric Co. in the Bloomfield (N. J.) Works.

Emil Reinhart is now connected with Timemaster, Inc., Chicago, as tool and process engineer.

Charles T. Evans, Jr., formerly manager of the carbide department of the Titusville plant of the Universal-Cyclops Steel Corp., has been appointed chief metallurgist for the Elliott Co., Jeannette, Pa.

Arthur S. Coffinberry has left Tube Turns, Inc., to become associate professor in the department of mining and metallurgical engineering at the University of Kentucky.

Andre Baudat, formerly supervisor of equipment engineering at the Boeing Aircraft Co. of Canada in Vancouver, B.C., has resigned his position to take charge of all manufacturing operations for the Sweden Freezer Mfg. Co. of Seattle, Wash.

Floyd Rose, formerly president of Vanadium-Alloys Steel Co., has been elected chairman of the board of Firth-Sterling Steel Co., McKeesport, Pa.

Marvin C. Moffett, formerly with the By-Products Steel Corp. and Lukens Steel Co., is now general manager for H. P. Turner Co., Atglen, Pa.

Paul R. Cutter, formerly assistant chief chemist of Consolidated-Vultee Aircraft Corp., Fort Worth, Texas, has joined the staff of the Hanson-Van Winkle-Munning Co., Matawan, N. J., as an electrochemist.

Edward J. Pavesic, formerly with the Studebaker Corp., is now a metallurgist for the Lindberg Steel Treating Co. in Chicago.

Robert L. Klein, formerly a research fellow at the Powder Metallurgy Laboratory, Stevens Institute of Technology, Hoboken, N. J., is now development engineer with the Massachusetts Pressed Powdered Metals Corp., Worcester, Mass.

Richard B. Weimer has opened consulting engineering offices in Cedar Rapids, Iowa, specializing in plant layouts and design of mining equipment.

R. H. Khuen, formerly sales manager of Chrysler Corp.'s powdered metal division, has formed his own company of engineering consultants known as R. H. Khuen Associates in Grosse Pointe, Mich.

Emil L. Savard is now employed by the Raytheon Mfg. Co., Boston, as a development engineer.

Personals

Donald L. Colwell has resigned as coordinator of conservation for the Navy Department to go to Tokyo with the U. S. Strategic Bombing Survey.

Francis C. Frary, director of research of Aluminum Co. of America, has been elected to receive the Perkin Medal of the Society of Chemical Industry.

W. R. Shimer has retired as metallurgical engineer in charge of sheet, strip and tin mill products, Bethlehem Steel Co. He is succeeded by Felix F. Aloi, formerly assistant metallurgical engineer.

John M. Parks, formerly engaged in teaching and research at Rensselaer Polytechnic Institute, has joined the staff of the American Society for Metals as editor of technical books.

Michael Kocsuta, formerly assistant engineering manager, Electric Boat Co., Groton, Conn., is now on the engineering staff of Industrial Rayon Corp., Cleveland.

Heinz V. Menking has resigned from American Magnesium Corp., Cleveland, and accepted a position with Reynolds Metals Co., Louisville, Ky., as manager of textile sales.

Stewart J. Stockett, formerly with General Electric Co., Ft. Wayne, Ind., as metallurgist, is now on the staff of Battelle Memorial Institute, Columbus, Ohio, as research engineer.

Appointed professor of metallurgy and head of the newly formed Institute for the Study of Metals at the University of Chicago: Cyril Stanley Smith, who has been head of the Metallurgy Division at Los Alamos (the atomic bomb project near Santa Fe, N. Mex.). Prior to the war he was research metallurgist for the American Brass Co., Waterbury, Conn.

William F. McAllister, engineer with the Wright Aeronautical Corp., has now joined Carl J. Kiefer Associates, Inc. of Cincinnati, as industrial project and development engineer.

Alan U. Seybolt has left the atomic bomb project, after two years, to become metallurgist at the Bayside, L. I. laboratory of Sylvania Electric Products, Inc.

Jack F. Smole, formerly plant manager at the P. A. Geier Co. of Cleveland, and his brother, Joseph F. Smole, formerly general machine shop foreman at the Clark Controller Co., are now partners in a newly formed concern, the Webster Products Co. of Cleveland.

John Howe Hall has resigned his position as assistant metallurgist at General Steel Castings Corp. and is resuming consulting practice in steel foundry work at Swarthmore, Pa.; he will be retained by General Steel Castings Corp. in a consulting capacity.

Fred C. Smith, formerly chief metallurgist of Tube Turns, Inc., Louisville, Ky., has now been appointed director of quality.

Edward K. Pryor, formerly a field engineer with the Charles Taylor and Sons Co., Cincinnati, has joined the staff of Battelle Memorial Institute, Columbus, Ohio, where he will engage in research in technical and economic statistics.

Heat Resistors

(*Continued from page 1095*)

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11. "The Book of Stainle Steels", edited by E. E. Thu American Society for Metals, 19

12. H. J. French, H. C. Cr and A. A. Peterson, "Creep in Fi Steels at Different Temperatures Natl. Bur. Standards Tech. Pap No. 362, 1928.

13. F. H. Norton, "The Cre of Steel at High Temperatures Mass. Inst. Technology, 1929.

14. J. Cournot and K. Sa gawa, "Contribution a l'Étude la Viscosité des Alliages à Te perature Elevée", 1925.

15. "Flow Characteristics Special Fe-Ni-Cr Alloys and So Steels at Elevated Temperature Natl. Bur. Standards Res. Pap No. 192, July 1930.

16. W. H. Hatfield, "Heat R sisting Steels", Brit. Inst. Fu 1938.

17. S. Craig Alexander, "Hi Temperature Conveyor Belts: Ind. Heating, July 1944.

18. Metal Progress Data Shee 1943.

19. Meuller-Burghaus, Sta and Eisen, Vol. 54, 1934, p. 822.

20. M. G. Bolinger and W Heilig, "Putting the Heat on Val Materials", Power, Vol. 82, No. 1938, p. 89; Ibid, Vol. 83, No. 1939, p. 86.

21. "Resumé of High Tempe ature Investigations Conduct During 1941-1942", Timken Roll Bearing Co.

22. "Resumé of High Tempe ature Investigations Conduct During 1942-43", Timken Roll Bearing Co.

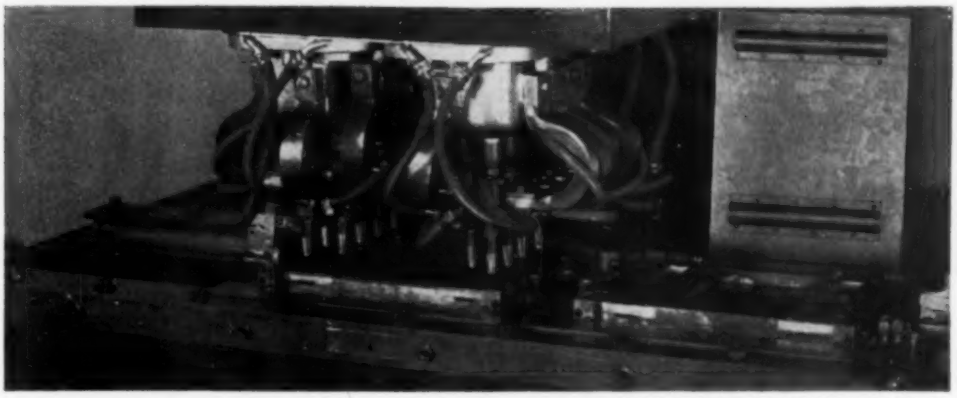
23. "Symposium on Effect Temperature on Metals", pu lished jointly by Am. Soc. Testin Materials and Am. Soc. Mec Engrs., 1931.

24. "Tables of Data on Chem ical Compositions, Physical an Mechanical Properties of Wroug Corrosion Resisting and Heat R sisting Chromium and Chromiu Nickel Steels", Committee A-10 Iron-Chromium, Iron-Chromiu Nickel and Related Alloys, Am Soc. Testing Matls., Dec. 1942.

25. "Timken Digest of Stee for High Temperature Service" Fourth Edition, Timken Rolle Bearing Co., 1939.

26. Universal-Cyclops Stee Corp. data. Allegheny Ludlu Steel Corp. data.

16 Spot Welds in One Operation 300 Assemblies an Hour...with



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MALLORY *Standard Resistance Welding Electrodes*

Light Alloy Wheels, Centrifugally Cast*

TWO TYPES of wheels were centrifugally cast in sand molds rotated on a vertical axis, using four aluminum-base alloys: DTD 304 (5% Cu, 0.1% Ti), 2L33 (12% Si, 0.03% Ti), DTD 300 (10% Mg) and RR50 (1% Cu, 2.5% Si, 0.8% Fe, 1% Ni, 0.2% Ti).

All alloys were melted in an electric furnace. Flux was used only for DTD300 and modified 2L33. In casting, an adequate height of down gate is essential, and this normally requires a deep central pouring head. The rate of pouring must be high. At rotational speeds causing pressures over 5 psi. on the outer surface of the cavity, a mold wash is essential to prevent penetration of metal into the sand; a wash of china clay and sodium silicate in water has been satisfactory. The addition of boric acid is desirable to prevent surface oxidation of the DTD300; this also improves the surface on DTD304 but has no effect on 2L33.

An advantage of the centrifugal process is that it enables thin sections to be run with quite cold metal. In centrifugal castings of spoked wheels, porosity tends to be concentrated at the junction of the arms with the rim; this cannot be eliminated by increasing the speed of rotation unless the cross-sections of the arms are larger than in normal practice for static castings. A working rule of one square inch cross-section in the arms for each 10 cubic inches of metal in the rim represents the minimum proportions. Of the alloys investigated, 2L33 suffers least and DTD300 most if the arms are of inadequate size. In general, the highest practicable speeds of rotation are desirable for light alloy castings, since the internal centrifugal pressure is naturally low for metal of low density. For these wheel patterns, a minimum peripheral speed of 2600 ft. per min. was desirable, giving 32 psi. pressure on the wall.

Centrifugal castings were made with a series of rotational speeds and casting temperatures. These were compared with static castings poured at different temperatures by making tensile tests on samples from three positions in each casting. All the samples were heat treated in a standardized program except those from the 2L33. Only slight improvements in mechanical properties as compared with static castings were obtained with RR50 and 2L33. Although there was only a minor increase in density, the test bars from the centrifugal castings of DTD304 showed an improvement of 15% in tensile strength and 78% in elongation over the static casting. The corresponding improvements in mechanical properties for DTD300 were 20 and 60%, respectively. When complete wheels were tested to destruction, the centrifugally cast wheels withstood a maximum load on the average 16% higher than the statically cast wheels.

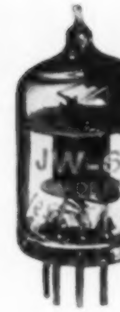
On the basis of these results, the alloys with high silicon are considered to have excellent founding characteristics for centrifugal casting. Alloys with copper have a tendency toward hot tearing and mid-section unsoundness which can be eliminated by using a high mold speed, a low casting temperature and a large feeding channel. The alloys with nickel are intermediate in properties and soundness between the alloys containing copper and those containing magnesium. The alloys with magnesium are not prone to cracking and, if surface oxidation is prevented, are not as liable as the alloys with copper to surface shrinkage defects.

The macrostructures of the centrifugal castings showed columnar crystals growing from inner vertical surfaces with equi-axial crystals in the outer zones. As the speed of rotation increased, the columnar crystals became longer and the equi-axial crystals smaller. With 2L33, centrifugal casting coarsened the eutectic structure (with the modification technique used).

A study of the structure and segregation of these alloys as well as castings made of lead-antimony, aluminum-silicon and aluminum-copper alloys led to an explanation of these structures based on the operation of a centrifuging action during the solidification interval when the densities of the liquid and the solid are different.

Although the centrifugal casting of light alloys in sand molds has not yet been of practical importance in England, there appears to the authors to be no insuperable difficulty likely to be encountered in its development.

*Abstracted from "The Centrifugal Casting of Aluminium Alloy Wheels in Sand Moulds", by L. Northcott and O. R. J. Lee, *Journal* of the Institute of Metals, Vol. 71, 1944, p. 93.

• • • 

TINY GIANT WITH A HISTORY

6AK5

Long before the war, the men who design your Bell Telephone System were looking for an electron tube with frequency capabilities never before attained. With it, they could transmit wide bands of telephone messages — several hundred of them — simultaneously through coaxial cable—economically, and over long distances.

They developed a tube which set a new standard in broad-band, high-frequency amplification. So minute that its electrode system had to be inspected under a magnifying glass, the tube could amplify either the voices of 480 people talking at the same time, or the patterns of television. Long-distance, broad-band transmission became a commercial reality.

Cross-section of Electrode System (five times actual size)

When war came, this tube excelled all others as an amplifier in certain military equipment. It then grew into the 6AK5, one of the great little tubes of the war. Besides producing 6AK5's in large quantities, the Western Electric responded to emergency needs of the Army and Navy by furnishing design specifications and production techniques to other manufacturers, of whom at least five reached quantity production. On every battlefront it helped our ships and planes to bring in radio signals.

Developing electron tubes of revolutionary design has been the steady job of Bell Laboratories scientists ever since they devised the first practical telephone amplifier over thirty years ago. Now tubes like the 6AK5 will help speed the living pictures of television, as well as hundreds of telephone conversations simultaneously over the coaxial and radio highways of the Bell Telephone System.

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Can Austenite and Martensite Resist Weld Cracks?*

THE mechanical properties a[illegible] transformation behavior of [illegible] air cooled steel with 0.32% C, 3.[illegible] Ni, 0.6% Cr, and 0.3% Mo we[illegible] studied at various stages befo[illegible] during and after the austenite [illegible] martensite transformation whi[illegible] started at about 600° F.

Tensile tests on the unstab[illegible] austenite showed that *(a)* the au[illegible]tenite has a low elastic limit a[illegible] good ductility; *(b)* transformati[illegible] is induced by plastic strain, [illegible] extent of the effect depending up[illegible] the sluggishness of the $\gamma \to \alpha$ chan[illegible] as indicated by the S-curve; a[illegible] *(c)* the bainite and martensi[illegible] formed by the transformation a[illegible] more elastic and less ductile th[illegible] the austenite. A series of tests we[illegible] made at 645° F. in which a defin[illegible] amount of transformation to baini[illegible] was allowed to occur in the speci[illegible]men before the tensile test w[illegible] made. Simple relations exist[illegible] between the mechanical properti[illegible] and the initial structural compo[illegible]tion of the specimen.

Tensile tests were also made [illegible] temperatures below 400° F. on ma[illegible]tensite prepared by air cooli[illegible] from 1560° F. The martensi[illegible] obtained by this treatment had [illegible] high tensile strength and appre[illegible]able ductility. The testing tempe[illegible]ture hardly affected the mechani[illegible] properties, except that a minimu[illegible] ductility was shown in the ra[illegible] of 275 to 210° F. — that is, imm[illegible]diately after completion (at 2[illegible] F.) of the change to martensi[illegible] This ductility change has be[illegible] shown to be mainly an effect [illegible] temperature.

The author concludes that fo[illegible] factors are important in produci[illegible] the cracks found when welding th[illegible] alloy steel: *(a)* Shrinkage strai[illegible] produced in the hardened zone [illegible] thermal contraction against exte[illegible]nal restraint; *(b)* inhomogeneity [illegible] the weld region; *(c)* capacity f[illegible] plastic deformation; and *(d)* t[illegible] breaking strength of the steel [illegible] temperature. In avoiding crackin[illegible] the ability to deform plastically [illegible] far more important than the brea[illegible]ing strength. Therefore, crackin[illegible] is exceedingly *(Cont. on page 113[illegible]*

*Abstracted from "Tensile Prope[illegible]ties of Unstable Austenite and Its Lo[illegible] Temperature Decomposition Products[illegible] by A. H. Cottrell, Iron and Steel Insti[illegible]tute Advance Copy, November 1944.

Weld Cracks

(From p. 1130) unlikely while th transformed zone is wholly or par tially austenitic, since this struc ture has ideal properties for strai accommodation. The stress ris will be much greater in the mar tensitic range, since the materia then has a high elastic limit and much lower ductility. The proper ties of the martensite found in thi steel were too good to account fo cracking in the hardened zone. was concluded that the martensit actually existing in the weld zone is much inferior mechanically t that produced in these tests. Thi inferiority is probably the result prior overheating in the region the weld deposit.

Pyrometry of a Steel Stream Entering a Mold*

As A RESULT of recognizing th fact that the quality of ingo and foundry castings is influence by the casting temperature, man steel works and foundries mak routine observations with the opt cal pyrometer of the temperatur of the casting stream. The accu racy of the optical pyrometer severely limited by the uncertain of the emissivity correction f the stream, more or less coate with oxide or slag, and obscure by smoke.

The normal quick immersi technique is satisfactory when th metal is poured over the lip of th ladle. But when the metal is bo tom poured, any tube put into th stream causes splashing.

This new apparatus is based o a standard runner-box ramme with "compo", and having a con cal refractory lining ¾ in. thic 10 in. deep, tapering to a minimu internal diameter of 2½ in. an provided with a cylindrical ca iron case. The refractory linin and cast iron case are drilled at a angle of 35° to the horizontal f the thermocouple tube. (A modifi cation for use when casting ingot has a conical refractory lining fitte into a steel frame.) *(Cont. on p. 113*

*Abstracted from "A Thermocoupl Method for the Measurement of Liqui Steel Casting-Stream Temperatures" by D. A. Oliver and T. Land; Iron an Steel Institute Advance Copy, Marc 1944.

Molten Steel

(Continued from p. 1132)

A platinum thermocouple, lightly sheathed in a silica tube 0.7 mm. thick, protrudes into the narrow part of the runner box lining, extending about ¾ in. into the stream. The e.m.f. generated at the hot junction is applied to a high speed amplifier and recorder which showed that a steady temperature was obtained in about 15 sec. In its present form, therefore, the method is applicable only to castings weighing over 500 lb. which take a considerable time to pour.

Two illustrations are given of applications. In the first, the true temperatures and optical pyrometer readings were used to determine the emissivity of a nickel-chromium-molybdenum steel. The emissivity was found to be about 0.38 and correlation was as good as could be expected in view of the uncertainty of the optical pyrometer readings. In the second, the ladle cooling of the steel was deduced from the recorded temperatures of the metal in the furnace and the thermocouple readings of the ladle stream. The average drop between the arc furnace and a ladle holding about 10 tons was 108° F.

The results showed gratifying consistency and the procedures proved simple.

Manufacture of Copper Powder*

AN INVESTIGATION was carried out to determine the most suitable conditions for the production of copper powder on a pilot plant scale. Copper is deposited from copper sulphate solutions as a powder when a high current density and low temperature are used with a solution of relatively low copper and high acid concentrations.

The most costly item in such production is likely to be the labor required for removing the copper from the cathode, washing, filtering and drying it. Most of the necessary powder is consumed in the electrodeposition tanks where about 1,000,000 ampere-hours of 1000-V units (where V is the tank voltage) are needed (Cont. on p. 1136)

*Abstracted from "Copper Powder — Commercial Preparation by Electrodeposition", by A. W. Hothersall and G. E. Gardam, *Metal Industry*, April 13, 1945, p. 234. A paper for the Electrodepositors' Technical Society.

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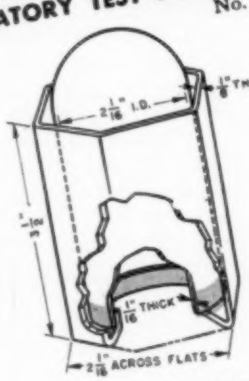

Operation: Braze dome to nose cup
Alloy: Silver Solder Grade 4
Flux: Fluoride
Temp. Limit: Flow Solder
Lepel Unit: 30 K.W. Input
Approx. Temperature: 1250° F
Heating Time: One piece, 13 sec.
4 pieces simultaneously, 55 sec.

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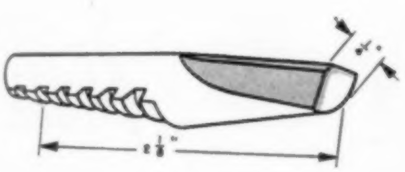
LABORATORY TEST REPORT
No. 1076



Operation: Harden Chuck Jaws
Steel Analysis: Tool Steel
Temperature: 1550°-1600° F
Quenching Medium: Water
Hardness Obtained: Rockwell C60
Depth of Hardness: Approx. 3/32"
K.W. Input: 7½
Heating Time: 10 sec.

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LABORATORY TEST REPORT
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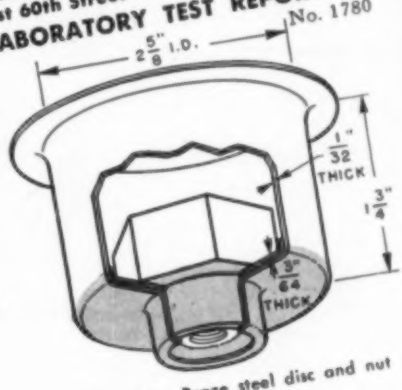

Operation: Braze steel disc and nut inside cup
Alloy: Silver Solder Grade 4
Flux: Fluoride
Temp. Limit: Flow Solder
Lepel Unit: 30 K.W. Input
Approx. Temperature: 1250° F
Heating Time: One piece, 16 sec.
6 pieces simultaneously, 92 sec.

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Copper Powder

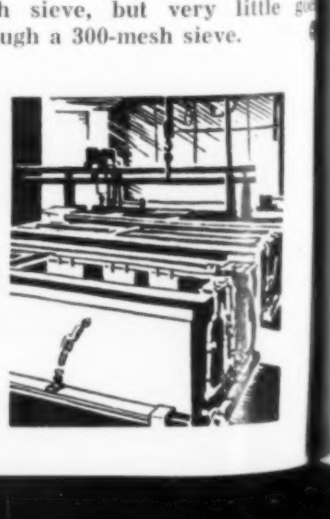
(From page 1134) to deposit one long ton of powder. Losses in recovering and washing the powder must be reduced to a minimum; discarded anodes must be recast. No study has been made of the anodic behavior of different grades of copper but probably a fairly crude grade can be used.

As a result of laboratory experiments, the following conditions are recommended: The solution should contain 40 to 60 g. per liter of $CuSO_4 \cdot 5H_2O$, and 140 to 160 g. of H_2SO_4. The cathode current density should 72 amp. per sq. ft.; temperature 85° F.; anode area not less than the cathode area; and interelectrode distance as small as possible. Both the sulphate and acid concentrations may be controlled by determining the acidity and specific gravity. It is probable that the copper sulphate will rise as the sulphuric acid decreases. This may be counteracted by discarding parts of the solution periodically or by using an insoluble lead anode occasionally.

The solution will have to be cooled by cooling coils or water cooled cathodes. The powder must be removed frequently from the cathodes — otherwise, a coherent deposit may be formed. In the laboratory tests, the cathode was brushed every 15 min. with a stiff bristle brush. It is necessary to remove the cathodes periodically (about every 12 hr.) for a thorough scouring.

The powder should be kept covered with solution until it is ready for washing. It settles rapidly so it may be efficiently washed by decantation. Washing should be completed and the powder dried with a minimum of delay. The inclusion of an intermediate wash of alkaline water gives a superior appearance to the powder and a lower oxygen content.

The final dried product flows easily and has an apparent density of 1.3 g./cc. The particle size is such that 90% passes through a 100 mesh sieve, but very little goes through a 300-mesh sieve.



Stretch-Forming*

THE stretch-forming methods used at Willow Run differ substantially from those used by other aircraft plants in that all the dies and blocks are made completely of steel. It is practically impossible to produce satisfactory curved aluminum parts without stretching to make them retain their final form.

A variety of stretch-forming operations are performed on mechanical presses by dies equipped with serrated jaws which grip the ends of the part and pull them lengthwise while the major portion of the part is firmly held between upper and lower die members. The same set of dies is used for preforming before heat treatment and the final stretch-forming. In preforming, the central section of the bottom die is shimmed to keep the serrated jaws from contacting each other. With this arrangement each end of the work is stretched ¼ in. while the main portion is being accurately formed in the die. The stretched ends with the marks from the jaw serrations are later trimmed off.

In another type of stretching, the lower jaws are forced outward at the same time that they are pushed down an inclined surface while the upper jaws are forced outward and upward. Stretch-forming may also be carried out without the use of sliding jaws. Stretch-forming machines designed for operation on extruded shapes are employed in a wide variety of types built to meet individual problems. A machine with a pulling capacity of 75 tons with hydraulically operated pulling head and a stationary head is used for stretch-straightening long hat sections twisted during heat treatment. The operation also increases the tensile strength by the 3 to 4% set. For certain stretch-forming operations, use is made of setups in which pressure is exerted from an overhead hydraulic unit to hold the part to its correct cross-section while horizontal hydraulic heads are pulling the shape lengthwise. A somewhat similar setup is used on a thin strip section. The part is placed between a bottom female die and an upper rubber-faced male die while the ends *(Cont. on p. 1140)*

*Abstracted from "Stretch-Forming Aluminum Alloy Shapes at Willow Run", by Charles O. Herb, *Machinery*, July 1945, p. 184.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To get full benefit of the low flow points of SIL-FOS (1300°F.) and EASY-FLO (1175°F.) you need a flux that also functions at a low temperature. HANDY FLUX starts to fuse and dissolve oxides at 800°F., and at 1100°F., is entirely fluid, and dissolves all refractory oxides rapidly and completely.
Handy Flux

Stretch-Forming

(Continued from page 1138)

are stretched by two hydraulic jaws. In some cases it is desirable to exert pressure horizontally against a form instead of on top.

These methods are not necessarily confined to the aircraft industry but could be applied to much postwar fabrication.

Distribution of Lead in Steel*

AN INVESTIGATION was made of the mode of occurrence of lead in a 0.25% carbon, 1% manganese steel ingot and in two wrought steels, one a high sulphur, and the other a manganese-molybdenum steel, both with and without lead. The maximum chemical segregation in the ingot was 0.04% Pb and did not follow completely the normal features of segregation. The distribution of lead was generally uniform except in the extreme base of the ingot.

The bottom-discarded billet of the manganese-molybdenum steel showed marked segregation, mainly toward the surface, chiefly of streaks of metallic lead containing particles of sulphides, oxides, and steel. Other, less numerous, segregated lead streaks consisted of particles of oxide and sulphide within a matrix of oxides or silicates. Lead was found associated with sulphide and silicate inclusions as lead and as oxide. The remaining samples were free from such massive segregation.

Normal microscopic methods failed to reveal lead unassociated with inclusions. Electrolytic etching in 10% ammonium acetate revealed particles believed to be lead which were not visible before etching. A new electrographic method was developed which produced a clear pattern of the lead particles in the ingot section. Gelatin paper soaked in 10% ammonium acetate was placed on blotting paper on an aluminum plate connected to the negative terminal of a battery. *(Continued on page 1142)*

*Abstracted from "Mode of Occurrence of Lead in Lead-Bearing Steels and the Mechanism of the Exudation Test", by W. E. Bardgett and R. E. Lismer, Iron and Steel Institute Advance Copy, March 1945.

Lead in Steel

(Continued from page 1140)

The micropolished specime was firmly pressed on the gelati paper and connected with the posi tive terminal by a brass plate. current of about two volts per s in. was applied for about 2 mi and the gelatin paper was the immersed in 5% ammonium aceta for ½ min., washed and soaked i a weak hydrogen sulphide solutio This method clearly revealed th distribution of lead in the ingot dark brown images. There was a increase in the particle size fro the surface to a position about 4 i below, with a gradual change fro a random to a slightly interde dritic structure. From this positi to the center, the distribution w generally similar.

Microscopic examination heated samples showed that th segregated lead in a billet sudden spurts out on the surface at a te perature of 455 to 465° F., the ste structure being slightly distorted a result of the exudation. An unse regated billet showed lead exud tion at 570 to 590° F., and in th ingot the lead spurted out at 615 625° F. with a partially interde dritic formation. The size of th exuded lead particles was marked less in the unsegregated than in th segregated specimens.

Semi-Continuous Casting*

CONTINUOUS casting has n been commercially successf until comparatively recently. Mo of the processes now aim to pr duce an ingot more suitable f subsequent fabrication than th material cast by older methods.

A truly continuous machine f casting ingots, such as the so-calle Junghans machine, requires an u limited amount of liquid metal a is suited only to the largest meta lurgical works. Most plants wi an intermittent supply of liqu metal have adopted the proce sometimes known as semi-contin ous casting or direct chilling. F several years, round ingots up to in. diameter and slabs 4½x18 i and 6x20 in. *(Cont. on page 114*

*Abstracted from "Semi-Contin ous Casting", by W. M. Doyle, *Met Industry*, June 15, 1945, p. 370 and Ju 22, 1945, p. 390.

Casting

(From p. 1142) have been so pr duced in most of the alumin alloys made in England by th author's firm, High Duty Alloy Ltd., and trade-named "Hidumi ium". It is necessary to crop o a few inches from these and sca less than ⅛ in. before rolling forging. Such round ingots gene ally may be extruded rough.

The three basic factors in th method are *(a)* pouring the liqu metal into a die to give the nece sary shape to the ingot, *(b)* chillin an outside layer of metal just thi enough to withstand the pressu of the liquid metal and *(c)* co pleting the solidification by b tom cooling as rapidly as possib The first item is a matter of expe ence in allowing for the prop amount of contraction — which larger than would be expected. T ideal conditions for the second a third items are never realized practice, mainly due to the phy cal constants affecting the h transfer and the cooling of the me below the die. The heat to extracted, together with the th mal conductivity and tensi strength of the metal at the elevat temperature, affects the optim speed of casting and the amount cooling water that will be nece sary to spray on the shell arou the solidifying metal. With co stant casting conditions, therm equilibrium establishes itself a the principal factor affecting he abstraction through the die is t overall thermal conductivi Below the die, however, the dif sivity constant or temperature co ductivity is more important. For 16-in. round ingot of alloy RR3 for example, about 18% of t original heat is lost during passa through the die and nearly 38% traveling through the first 6½ i just below the die.

In continuous casting, the ing is subjected to higher quenchin stresses than one cast by any othe method. The surface is under hig residual compressive stresses; the decrease nearer to the center, th become tensile stresses reaching maximum in the center. Crack naturally will occur where th residual tensile stress is highe than the tensile stress of the mat rial at that temperature.

Susceptibility to cracking mainly a function of the compos tion; thus alloys with a high mag nesium silicide content are much more liable to cracking than alloy containing less *(Cont. on p. 114*

Casting

(From p. 1146) magnesium. Alloy with massive insoluble compound are difficult to cast by this process. The alloys easiest to cast are pure metals and alloys with a narrow freezing range.

X-ray tests of a direct chilled ingot, 4⅝ in. diameter, of alloy RR59 showed the compressive hoop and longitudinal stresses were of the same order of magnitude and their sum amounted to 46,600 psi at the surface, dropping rapidly to zero at a layer about 1 in. from the surface. The center tensile stress was 23,500 psi. A check on these stresses by progressive boring gave about the same compressive stresses but double the tensile stress. These stresses could be halved by increasing the length of the die four times but the advantages of continuous casting would then be lost. If ingots are to be stored, it is customary to anneal at 350° C. to remove these high internal stresses.

A continuously cast slab of alloy DTD390 showed the typical heavy inverse segregation on the outer layer, but this can be removed by an ⅛-in. cut. Otherwise, no segregation occurs longitudinally. There is a slight segregation from the center outward, which compares favorably with the segregation in slabs cast in molds.

Aluminum alloy ingots made by the continuous process have a fine equi-axed structure with no shrinkage cavities. Micro-constituents are small and evenly dispersed. The macrostructure of a 16-in. diameter ingot of alloy RR56 was clearly superior to that of chill cast or die cast ingots.

The future prospects of continuous casting are encouraging, as there are very real advantages in machining, ease of fabrication, improved structure and mechanical properties of the final product. It has already set entirely new standards of perfection.

Nickel in the B-29

METALLURGY was but one problem encountered in the production of the B-29, its cargo counterpart the C-97, and the passenger version C-377, but it was a basic one for it was essential that the designers know what they could expect *(Cont. on page 115*

★Abstracted from "Material Problems Solved in a Superfortress", *In* Vol. 19, No. 4, p. 4.

ALLOYS THE QUALITY NAMES IN ALLOY FOR HEAT CORROSION ABRASION **X-ite**

November Raspberries

Nasty Doesn't Live Here Anymore

CREDIT to the Boston Maine railroad who took occasion o advise their employees that "open season" on their atrons closed with the war. The lofty disdain, the supeior sneer, the stupid wisecrack and the dirty look generally ccompanied with "Don't you know there's a war on?" ould no longer greet anybody at any counter anywhere. Valking into a railroad station and getting courteous, fficient service with a smile so shocked me that I took nother look at the clerk. He wore a discharge button. What happened to the insolent sourpuss who stood behind ose bars?" I asked. "Nasty doesn't live here anymore", id the ex-G.I. and added "This seems like a picnic, it's ood to be back, the Public is swell."

The Berries

THIRTY raspberries to a large dish. They come from r 7 ft. bushes bearing two crops. We picked them 'till ovember 12th last year. Plant a few good raspberry shes and let them spread. These and everbearing strawrries are two of the best numbers in our Victory Garden. e'll send raspberry canes or strawberry plants from prize ck next spring, with our compliments, to the first ten S.M. members who write.

You Can't Fool The Scrap Dealer

THIS is not written to criticize competitors or furnace ilders. All the alloy that could be made by anybody th a furnace to melt it from any scrap available was eded in the war effort. Many a marginal operator or grade producer made stuff that was "worth its weight gold" when we had to have it. But users should face ts. The facts are: "35ni-15cr" scrap is bringing from to 3½¢ per pound from the scrap dealers, *yet the P.A. ceiling is 9¢!* It contains the required minimum of kel and chromium and can be recast into fair *appearing* stings for 6 to 8¢ per pound under new material. (This ure, incidentally, about equals the spread in the current y prices between those who make alloy for low first cost d those that try honestly to make it for low ultimate cost.

REMEMBER, W.P.B. ordered alloy manufacturers to use ap, that available scrap was poor, and that remelting by al foundry methods did it no good. Hundreds of war stitute pusher furnace trays, for example, from Texas Canada, have failed prematurely and scrap dealers offer scrap for remelting. It is headed back to other buyers o will probably pay within 5¢ or 10¢ of X-ite prices for stings made from it. *They may kid the customers but the Scrap Dealers!*

LARGE quantities of alloy trays were bought through nace builders who, of necessity, purchased them from suppliers of ordinary furnace parts. (The furnace ts usually remain at temperature, whereas the trays intermittently heated and cooled and frequently quenched.) Customers paid X-ite prices or higher. Don't blame your furnace builder. Now you can replace this stuff with G.A. trays.

INCIDENTALLY, there is not a single General Alloys tray installation in which we have had any comebacks or adjustments made through the war period and that includes powder-metallurgy trays at 2150° F. Compare this with your own tray experience.

"Esquire"—Nov. '45

"ESQUIRE" issue of Nov. 1945 carries an interesting and beautifully illustrated story about our early automobiles by John Leathers, Manager, Precision Casting Department, G.A. Co., who, incidentally, set up precision casting for Winchester Arms. John drives a supercharged Mercedes, 250 H.P., walks home occasionally.

Vacucast Tubes

YOU might not guess looking at the combustion tubes shown here that they were sucked out of the ladle by vacuum into a metal mold. The vacuum released and the surplus metal run out, when the metal had solidified to the desired wall section. (Patent Pending)

NOW we have the capacity to accept orders for rotary gas carburizing retorts and solicit your inquiries.

H. H. HARRIS.

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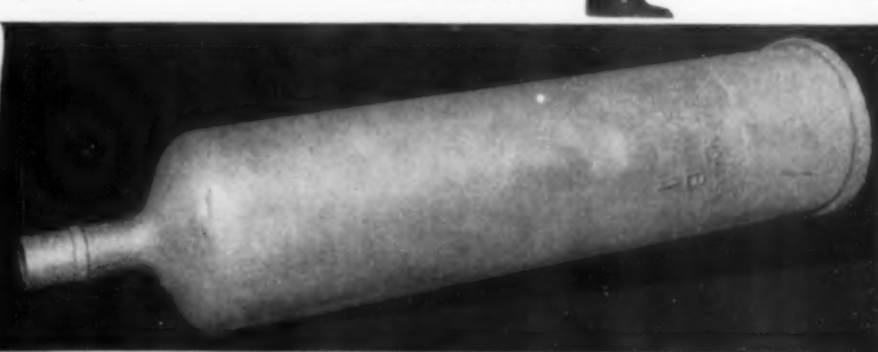

FOOTSTEPS OF GENERAL ALLOYS MARK THE PATH OF AN INDUSTRY

Nickel in the B-29

(From p. 1148) of their materials. There are scores of metals and alloys used on a B-29 ranging from platinum and silver to iron. Nickel alloys, for instance, are found all over the ship.

Nickel alloy steels, nickel-aluminum alloys, and nickel alloy cast iron are found in the engines. The elaborate electrical circuits need various types of nickel alloys, some with high electrical conductivity, some with high electrical resistivity, and others with specific coefficients of expansion. Navigational and operational controls likewise demand a wide combination of properties. Strong, corrosion resistant, non-magnetic alloys such as K-Monel are essential for some uses. Inconel and chromium-nickel stainless steels are used for exhaust systems where resistance to exhaust gases up to 1600° F. is required.

Turbo-superchargers are exposed to cold air and hot gases at over 1200° F. Stainless steel, Inconel and Ni-Resist cast iron are used in their construction. Stainless steels are also used for fire walls, cowlings, and engine nacelles to give protection against the heat of the engines, the hot exhaust flame, and to avoid fire hazards.

The landing gear assembly, including parts made of 2% nickel-chromium-molybdenum steel, carburized 3½% nickel steel, and 18-8, welded with stainless steel, takes terrific punishment. The brakes are made of a nickel-chromium-molybdenum cast iron centrifugally cast against a steel shell, and must resist heat checking, galling, and frictional wear.

The first frame for the noses was made of a cast light weight alloy but proved unsatisfactory from a production angle. The solution was found in a welded frame of a 1.5% nickel-chromium-molybdenum steel. Not only was the yield strength increased from 17,000 psi. to 135,000 psi. but considerably greater reliability in production was obtained.

Inconel spring wire is used in the cabin heating system while Monel bars provide the basic stock for electric circuit breakers. Monel is used for the fuel line strainers. Among the largest high nickel alloy parts is the lubricating oil cooler with a Monel shell and copper cooling tubes. The assembly meets the requirements of ease of forming, welding, and soft soldering as well as resistance to corrosion.